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MONTEREY, CALIFORNIA

THESIS

MANPOWER ANALYSIS USING DISCRETE SIMULATION

by

Gregory A. Bauer

December 2015

Thesis Co-Advisors:	Arnold H. Buss
	Paul J. Sanchez
Second Reader:	Steven E. Pilnick

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MANPOWER ANALYSIS USING DISCRETE SIMULATION

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Submitted in partial fulfillment of the
requirements for the degree of

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NAVAL POSTGRADUATE SCHOOL
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Career management and progression of Supply Corps officers is performed by PERS-4412, considering such factors of interest as number of accessions to make and tour lengths. To study the effect of policy choices on the underlying system, this thesis focused on model building using Discrete Event Simulation (DES) and experimentation using Design of Experiments (DOE). We derived five metamodels to identify the most important factors that describe the personnel system response (model outputs) as functions of the policy choices (simulation inputs). Multiple regressions and the resultant profiler allowed fine-tuning of the inputs to arrive at personnel policy recommendations in which all but one of the system objectives were met.

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LIST OF ACRONYMS AND ABBREVIATIONS

1OP	First Operational Tour
2OP	Second Operational Tour
ACC	Accessions
BOLC	Basic Officer Leadership Course
BQC	Basic Qualification Course
CNO	Chief of Naval Operations
DELREP	Delayed Reporting
DES	Discrete Event Simulation
FEL	Future Event List
FIFO	First-In First-Out
FTS	Full Time Support
GRADRATE	Graduation Rate
INT	Interim Tour
LCM	Life Cycle Management
MOE	Measure of Effectiveness
NOLH	Nearly Orthogonal Latin Hypercube
NPS	Naval Postgraduate School
NROTC	Naval Reserve Officer Training Corps
OAIS	Officer Assignment Information System
ODIS	Online Distribution Information System
OCS	Officer Candidate School
PCS	Permanent Change of Station
PEBD	Pay Entry Base Date
PRD	Projected Rotation Date
SODHC	Supply Officer Department Head Course
STA-21	Seaman to Admiral (21st century)
SQL	Structured Query Language
TOS	Time on Station

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EXECUTIVE SUMMARY

This thesis provides Supply Corps community managers with the advanced tools necessary to assess policy decisions affecting the careers of officers from the point of accession until their accumulated experience has prepared them for entry into the junior executive ranks—more commonly known as the rank of Lieutenant Commander. This summary briefly focuses on the commission of this study, the why, followed by our approach to providing insight, the how. Our sponsor, PERS-4412, is one of many community managers that is solely responsible for ensuring that all Supply Corps officers achieve a broad base of experience in terms of leadership, responsibility, and the attainment of technical skills. Our research presents a versatile tool that provides analytical insight into the effects policy decisions have on the timing of important job assignments within officer careers.

When PERS-4412 asked, "What should each of the tour lengths be?" our approach in providing an answer involved building a simulation model using Simkit—a widely available library based in the Java programming language for building Discrete Event Simulation (DES) models. By overriding existing methods and the development of our own Java classes, we adapted a Simkit library, and were able to model the system of progressive job assignments, better known as "detailing."

During model development, assumptions were made to simplify the model. Each officer who entered the system followed a rigid set of business rules where completion of one job assignment led to another, similar to successive assignments in reality. Each job assignment was further classified into three categories: First Operational Tours, Interim Tours, and Second Operational Tours. Inputs to the model consisted of the size of the graduating class, the frequency with which each class was graduated, and the prescribed or desired length for each tour.

Placement of officers in each tour was implemented by use of a FIFO queue where the first to enter the queue is the first to leave. Within the framework of DES modeling, movement between job assignments and all the underlying business rules are

implemented via events. For each officer entering the system, the timing between events was handled by use of an Event List (a Simkit feature) where the timing of the event was projected into the future. The Event List allows us to determine the proper order in which to execute events and the outputs of the model were comprised of data collected from the various events.

Outputs of our model consisted of Mean Time on Station (average tour lengths) for each tour (x3), Mean Interim Queue Size, and Maximum Unmet Demand within the Second Operational Tour. Mean tour lengths were reviewed to gauge our ability to meet the prescribed tour lengths, or as an alternative viewpoint, to assess the result of a particular combination of input factors—a viewpoint common to all our outputs. The Interim Queue acted as a buffer, where any growth or decrease in community size was projected in the mean size of the Interim Queue. Maximum Unmet Demand was measured by the number of officers waiting for a relief in the Second Operational Tour.

To produce the data for further analysis, we conducted 3300 experiments with our model using Design of Experiments (DOE). Our experimental design consisted of 33 design points, replicated 100 times each, where each point represented a carefully selected unique combination of our inputs. From the data that was collected, we developed five regression models (metamodels) that provided a powerful set of tools possessing predictive capacity. Each metamodel represented a single output as a function of the inputs.

The metamodels provided insight into which factors had the greatest influence on each of the five outputs. In combination, they offered the ability to see the real-time effects that each of the inputs had on all of the outputs when varied in isolation or in combination with the other inputs.

Our Measure of Effectiveness (MOE) objectives at the outset were to: 1) minimize the difference between the observed tour length means and the prescribed tour lengths; 2) minimize the personnel costs associated with fluctuations in community growth (Interim queue size); and 3) minimize Mean Maximum Unmet Demand. We placed priority on meeting the MOE objective minimizing personnel costs

(controlling the size of the Interim queue). Using our composite model—consisting of the five individual metamodels we developed—we arrived at one of many solutions where all but one of MOE objectives were met— minimizing Mean Maximum Unmet Demand. Using our model, we were able to determine the following criteria for what each tour length should include.

- The size of each graduating class should be 35 students.
- A class should graduate every 3 months.
- The Mean First Operational Tour length is entirely dependent on the size of the graduating class and the graduation rate irrespective of what is prescribed by policy.
- The target length of the Interim tour should be 48 months.
- The target length of the Second Operational tour should 30 months.

As an additional benefit, the model's predictive capabilities and their associated profilers were themselves dynamic tools that the end user could utilize to address a wide variety of what-if questions.

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To my friend Phil Knauss: better late than never….

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I. INTRODUCTION

A. SUPPLY CORPS COMMUNITY

PERS-4412, a subsidiary of the greater U.S. Navy personnel management organization based in Millington, Tennessee, deals specifically with the assignment and career management of 2,369 regular active-duty Supply Corps officers, in addition to 1,429 Selected Reserve, Limited Duty Officers, Chief Warrant Officers, and Full-Time Support (FTS) officers. A primary goal of PERS-4412 is to balance the number of accessions into the community, the length of time an officer spends at an assignment or billet, and the progression of assignments of increasing levels of responsibility. As a supporting organization, the Supply Corps has recently emphasized and echoed the Chief of Naval Operation's (CNO) strategic tenets of "Warfighting First, Operate Forward, and Be Ready." To this end, the Supply Corps community must develop leaders who possess the experience and knowledge of forward-deployed operational support of the war fighter.

Currently, the Supply Corps community provides for the succession and relief of its active duty element through the following accession points of entry: 1) The United States Naval Academy; 2) Officer Candidate School (OCS); and 3) Naval Reserve Officers Training Corps (NROTC). From the accession point, all Supply Corps Officers will attend the Supply Officer Basic Qualification Course (BQC) located in Newport, Rhode Island. After successful completion of BQC, a majority of officers will be assigned or detailed to a number of varied sea-going or operational billets, from a nuclear powered submarine to a destroyer, cruiser, or aircraft carrier. For simplicity in discussion, the first operational, shore, and second operational assignments will be referred to as the First Operational Tour, Interim Tour, and Second Operational Tour, respectively. In the First and Second Operational Tour, the incumbent officer can be expected to serve on a sea-based ship or submarine. In the Interim Tour, the incumbent officer is normally assigned to a shore-based support organization but may be assigned to another forward-deployed, sea-going operational billet when the supply of qualified officers is insufficient to meet demand.

Concurrently with attaining the three assignments listed above, an officer can be expected to progress through the junior ranks of Ensign (ENS/O1), Lieutenant Junior Grade (LTJG/O2), and Lieutenant (LT/O3) before promotion to the grade of Lieutenant Commander (LCDR/O4). For the purposes of our discussion, an officer will progress through the operational assignments above without regard to rank. To clarify the scope of our discussion, only the officer grades of O1 through O3 in the active duty element are examined.

B. A COMPETITIVE ENVIRONMENT FOR RESOURCES UNDER AN AUSTERE ENVIRONMENT

As a result of overall global economic activity declining during the post-2008 recession, termination of combat operations in Iraq on September 1, 2010, subsequent drawdown of forces in Afghanistan, and the response of the United States Congress to budget deficits and national debt, the United States Navy is now facing reductions in the overall defense budget, prompting human resource and community managers across the Navy to begin to address the upcoming cuts to manpower and personnel. As one of the smaller communities, and with a supporting role to the warfighter, the Supply Corps arguably faces even greater pressure to do more with less. In response, the Director of Officer Plans (PERS-4412) has commissioned a study to examine the behavior of the system of assignment and career progression for Supply Corps officers.

C. EXAMINATION OF THE STATUS QUO—MANAGEMENT OF SUPPLY CORPS PERSONNEL

To better evaluate any proposed policy changes to the management of Supply Corps personnel, we must first examine complications emanating from current policy decisions. While this is not an exhaustive list of competing interests, for a start, a community manager must balance the need for officers in specific billets, and the time spent in that billet due to the number of new accessions to the community, with the apparent objective of having sufficient personnel flowing through the system. Assigning officers to specific billets should neither leave any billet unnecessarily vacant, nor truncate the length of the tour, nor should it jeopardize the operational experience gained

through on-the-job immersion. Further constraint to this dynamic is the number of funded billets authorized for a given year, which easily translates to the number of accessions required to meet this goal for the current year. No real-time solution exists for the study of a proposed policy change or the effect it has on the system over time.

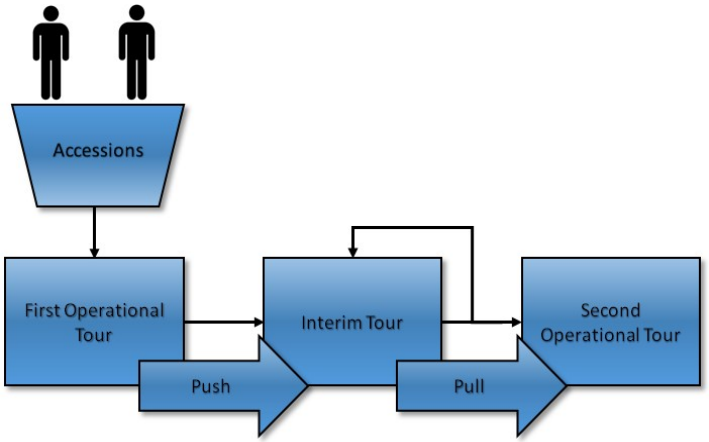
Currently, PERS-4412 has proposed, and practices, the assignment of personnel to the First Operational Tour for 30–36 months. For assignment to an Interim Tour, an officer is expected to serve in that billet for 12–36 months. As a Lieutenant assigned to a Second Operational Tour, an officer can expect to serve in that billet for 18–36 months or more based on the needs of the community manager. This particular policy, or any other policy for that matter, has a profound effect on the system under study.

Bringing both the First and Second Operational Tours back into focus, and in keeping with the CNO's operational emphasis, the Supply Corps has prioritized the assignment of personnel to these tours. Specifically, officers in their First Operational Tour cannot be transferred to a follow-on billet until a relief has been identified. An officer in their Second Operational Tour is generally relieved at their Projected Rotation Date (PRD)—a forecasted date to be relieved of duty—then identified and assigned upon generation of the orders authorizing personnel transfers. To facilitate such a policy, PERS-4412 identifies reliefs to be drawn from officers in their Interim Tour. As previously mentioned, officers being assigned to an Interim Tour can be reassigned to a subsequent Interim Tour. The determining factor when assigning an Interim Tour officer to a Second Operational Tour is whether an incumbent requires a relief in the near future. If no relief is required at the Second Operational Tour, then that officer in the Interim Tour will be reassigned to another Interim Tour.

What generally ensues is an exercise in matching PRDs to ensure the system of personnel assignment runs smoothly, where officers in their First Operational Tour are "pushed" into the Interim Tour, and officers currently in their Interim Tour are "pulled" to relieve officers currently in their Second Operational Tour. Figure 1 is a graphical depiction of the system under study. In cases where reliefs for Second Operational Tour officers are not available within the Interim Tour, reliefs are "pulled" from the First Operational Tour.

To clarify, since no entity (officer) can arrive at the Second Operational Tour until the module is ready to receive, it is a “pull” system, while the 1OP module is a “push” system. An officer is assigned to an Interim Tour freely when ready. Unique to the Interim module is the endless loop (i.e., an entity will be continuously reassigned an Interim Tour until the 2OP module is ready to receive).

Figure 1. Assignment of Supply Corps Personnel Grades O1–O3



PERS-4412 tracks officer personnel data using a legacy management information system known as the Officer Assignment Information System (OAIS). OAIS is a sub-module of the larger Online Distribution Information System (ODIS); a database that allows an authorized user the ability to perform a variety of large OAIS query operations. Analysis of the data retrieved from a query is subsequently performed using Microsoft Access. Foremost among the questions from PERS-4412, is “how long should the tour lengths be for each job assignment while minimizing variability over time?” Namely, PERS-4412 seeks to identify the time spent at each operational assignment, while minimizing expansion and contraction of the total number of billets needed to place new accessions. In a real-world application, this last concept sometimes translates into a deficit, but usually into a surplus of officers in the system.

D. LITERATURE REVIEW

While several studies of manpower modeling were conducted over the past decade, most are optimization models (i.e., a model that provides the mathematically optimal response, given a set of input parameters and whose output is deterministic). The focus of our study is to examine the empirical distributions underlying the behavior of the system.

Additionally, the available literature does not provide a wide breadth of academic study of Discrete Event Simulation based (DES) manpower models. A study by William I. Lewis, Jr. (2005) sought to examine the performance of the Army's transitional manning strategy known then as Life Cycle Manning (LCM). Lewis' approach to studying this problem was based on a DES model using primary elements from queuing theory with the aim of determining the mean delay-in-queue for officers transitioning from the Basic Officer Leadership Course (BOLC) to their first operational unit (2005). Our model will use similar methodologies in model development, while addressing the meta-behavior of the system as a whole, instead of a single output statistic of delay-in-queue. The resulting distribution of the response variables (i.e., Maximum Unmet Demand, Mean Time On Station (TOS), and Mean Interim Queue Size) will, over time, allow decision makers to view the effects of current manpower planning policies.

Given the criteria provided by PERS-4412, our model will capture the variance inherent in the system being studied, allow adjustment of the input parameters, and provide an output that would allow decision makers to assess the risk involved in their decisions. The development of this model will closely mirror the approach using elements from the works by Buss (2011) and Sanchez (2007), while using appropriate methodologies as discussed in Alexopoulos and Seila (1998, 2000), Sanchez (2005), and Sanchez and Wan (2011).

E. THESIS OVERVIEW

Chapter II provides an overview of our model to include methodology, concepts, and substructures. Chapter III lays the foundation for analysis. Chapter IV presents results and recommendations for further consideration.

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II. SIMULATION MODEL

A. PURPOSE

One of many core decisions a community manager must make is about the duration of time an officer should spend at each operational assignment, to reduce or eliminate any bottlenecks or points of constriction on the available manpower to fill each authorized billet. Additionally, the community manager must fill the available quotas or authorized billets with the available manpower, while sustaining upward career progression, through the assignment of personnel in billets of increasing responsibility; made possible by way of new accessions to the system.

From each successive assignment and relief cycle to the next, what is an ideal tour length for each operational assignment that minimizes the variability of the actual time spent in each billet? Given a change in the number of accessions—graduation rate from the accession point, and tour lengths of each job assignment—which of these policies also minimizes expansion and contraction of the number of billets required in placing each new accession into gainful employment? Through simulation, we intend to provide insight to policy makers regarding these questions.

In this chapter, we look at the time components—or career path dynamics—of a typical career path, to provide a better understanding of how our resultant model should behave. Given these career path dynamics, we provide a basis for the appropriateness of using a DES followed by a component-based breakdown of the resultant model, in order to offer the reader additional insight into how the individual modules and their associated characteristics interact.

We also provide a full account of the input parameters, states, and outputs, along with their associated definitions and classifications. Following this account, we also illustrate the connection between our model and how it will address our fundamental research questions in terms of Measures of Effectiveness (MOE).

B. CAREER PATH DYNAMICS

Career path dynamics consist of examining the extrinsic and intrinsic forces affecting a Supply Corps Officer's career, covering the point of accession into the Supply Corps, to the point of a successful completion of a Second Operational Tour. Where warranted, we will provide additional descriptive information to include assumptions made by the modeler, or as provided by PERS-4412.

1. Accessions

For commission into the Regular Active Duty Component, an Officer Candidate will have been inducted into naval service through the Naval Academy, NROTC, OCS, STA-21, or as a lateral transfer from another service. For each of these points of entry, an officer candidate will be considered in a training status and not available for assignment to any billet.

For modeling purposes, and at the direction of PERS-4412, officers are assumed to have successfully completed their accession point training, and are immediately available for assignment in consistent batches, at specified time intervals (i.e., quarterly), while holding attrition negligible.

For the purposes of modeling each new accession to the system, the Arrival Creator module is described later to facilitate the above behavior, and is thoroughly explained in this chapter with an accompanying event graph.

2. Supply Corps School

After graduation from an accession source, newly commissioned Supply Corps officers can expect to be assigned to the BQC located in Newport, Rhode Island. The entire duration of instruction spans 24 weeks, with a high probability of additional time spent waiting in the local area for a class start date, and after completion, waiting for a transfer date. Graduation normally occurs one week after course completion, adding to the posterior time in the local area. Additionally, if an officer is elected to serve onboard a nuclear powered submarine, that officer can expect to attend the Supply Officer

Department Head Course (SODHC). The duration of this course adds five weeks to the total time spent in Newport, Rhode Island.

For the purposes of modeling this operational assignment, it is assumed that officers graduating from the Navy Supply Corps School will take voluntary leave and be assigned to their First Operational Tour. In practice, each officer from the graduating class effectively pushes out the incumbent officer from the First Operational Tour. If no relief is provided, an incumbent officer in their First Operational Tour must continue to serve in that billet until a relief is made available. The time spent in Supply Corps School is modeled within the Batch Process Module, and is described in this chapter with an accompanying event graph.

3. Leave

Current leave policy, used in connection with a Permanent Change of Station (PCS), is governed by MILPERSMAN 1320–308. Except under the following circumstances, leave used in connection to a PCS is also known as Delay in Reporting (DELREP), and is to be granted in the amount up to 30 days in connection with a PCS, except under the following circumstances, quoted here:

- Initial orders to active duty
- Hospitalization
- Second PCS move within a 12-month period
- Homeport changes
- Unusual circumstances such as death or illness, detachment for cause, emergency, or key operational dates
- Upon completion or non-completion of flight training
- Detachment from certain activities in Japan (MILPERSMAN 1320–308, 2007)

When leave in connection to a PCS is elected by an active duty member, the duration of leave is solely at the discretion of the member.

For the purposes of modeling this behavior, it is assumed that each member elects to take leave following a triangular distribution with $a = 0$, $c = 0.75$, and $b = 30$, where a triangular distribution can be described as a continuous probability distribution with lower limit *a*, upper limit *b*, and mode *c*, where $a < b$ and $a \leq c \leq b$. Each time an officer elects to take leave a method call is made to one of our own Java classes, appropriately named "Leave Generator," returning a random number equal to the amount of leave elected. Interested readers may refer to (Forbes, Evans, Hastings & Peacock, 2010) for a more comprehensive treatment of statistical distributions to include the triangular distribution.

4. First Operational Tour

If assigned to a nuclear powered submarine or mine sweeper, an officer, based on current PERS-4412 policy, can expect to spend 18–30 months onboard. If assigned to any other hull type, an officer can expect to serve onboard for 24 months.

For modeling purposes, and at the direction of PERS-4412, each member reporting to their First Operational Tour will be assigned to that tour for equal amounts of time. An incumbent officer cannot transfer from their First Operational Tour, until a relief has been identified, taken leave if elected, and reported to the command or organization. A queue implemented within the Entity Server 1OP module is constructed to model this behavior and is described later in this chapter with the accompanying event graph.

5. Interim Tour

Interim Tours consist of a number of different types of duty. For example, an officer can serve as an aide to an Admiral, pursue graduate education at the Naval Postgraduate School (NPS), perform a variety of duties under the logistics banner at a shore-based support facility, or be assigned to an internship designed to give the selected officer an opportunity to gain an advanced skill set in a given specialization. Unique to the Interim Tour, is the flexibility a community manager has in adjusting for the length of time an officer spends in this assignment. As per current PERS-4412 policy, the time an

officer spends in an Interim Tour can be as short as 12 months if assigned as an Admiral's aide, or as long as 27 months if pursuing a Master's degree from NPS. An incumbent officer serving in an Interim Tour may continue on to the next operational assignment at a Second Operational Tour or be reassigned to another Interim Tour.

For the purposes of modeling this operational assignment, an incumbent officer will transfer to another Interim Tour once their Projected Rotation Date (PRD) has been reached, after taking leave if elected. For simplicity and at the direction of PERS-4412, each officer reporting to an Interim Tour will spend equal amounts of time in that Tour, treating all tours homogenously. A queue implemented within the Entity Server INT module is constructed to model this behavior and is described later in this chapter with the accompanying event graph.

6. Second Operational Tour

Being assigned to the Second Operational Tour normally provides the Supply Corps officer with experience serving in a greater leadership role, by serving as department head in the surface fleet onboard a destroyer or frigate, directly accountable to the Commanding Officer. Serving onboard a large-deck combatant as a department head is reserved for officers in the grade of O5, who have been screened and selected through a board process. According to current PERS-4412 policy, an officer can expect to serve onboard for no less than 18 months.

For modeling purposes, and at the direction of PERS-4412, each officer will transfer at their PRD, gaining relief from an officer in their Interim Tour, or in rare cases from an officer from their First Operational Tour, a practice known as cross-decking, and often referred to as back-to-back sea tours. Once the Interim Tour officer is pulled from the Interim queue, and takes leave if elected, the incumbent officer in their Second Operational Tour can be relieved and transferred. Once the Second Operational Tour officer has been transferred, we no longer take interest in his or her career dynamics. A queue implemented within the Entity Server 2OP module is constructed to facilitate the above behavior and is later described in this chapter with an accompanying event graph.

Table 1 is a summary of current PERS-4412 assignment policy by operational assignment and billet type.

Table 1. Current Tour Length Assignment Policy—PERS-4412

Operational assignment	Billet Type	Current Policy
Basic Qualification Course	School	24 Weeks of Instruction
First Operational Tour	Frigate	24 Months of Duty
	Destroyer	24 Months of Duty
	Aircraft Carrier	24 Months of Duty
	Submarine	30 Months of Duty
	Minesweeper	30 Months of Duty
Interim Tour	Admiral's Aide	12 Months of Duty
	Internship	24 Months of Duty
	Graduate School	18 Months of Duty
	Shore Support Tour	36 Months of Duty
Second Operational Tour	Frigate	24 Months of Duty
	Destroyer	24 Months of Duty
	Aircraft Carrier	24 Months of Duty

C. MODELING ASSUMPTIONS

In designing the simulation model, certain assumptions had to be made, whether it was because there was a lack of data, or to simplify implementation. With this end in mind, PERS 4412 provided and approved the following assumptions, or they were based on the author's own experience within the community itself.

- New Accessions (ACC) made available to the system, regardless of source, and based on a quarterly schedule, are defined here as the Graduation Rate (Grad Rate).
- Each new accession to the system would be required to report to their First Operational Tour and would be assigned to that that billet for the same amount of time as every other accession, and would not be relieved from that billet until a new accession to the system had arrived as a relief. Officers are not required to serve in the First Operational Tour for a minimum amount of time.
- Officers being relieved from their First Operational Tour would report to their Interim Tour, and would be assigned to that billet for the same

amount of time as other new accessions to the Interim Tour. Officers are not required to serve in the billet for the entire duration.

- Officers currently serving in an Interim Tour billet would continuously recycle through the Interim billets until an available billet in the Second Operational Tour becomes available. Interim Tour lengths would be equal in length. Expansion and contraction in the number of Interim Tour billets would be the primary means of measuring variability in the system.

- Officers currently serving in their Second Operational Tour would be assigned to that billet for the same amount of time as every other officer. When a Second Operational Tour officer's PRD was reached, a relief would be immediately pulled from the Interim Tour, after accounting for any leave taken by the relieving officer. Reliefs are pulled from the Interim Tour from the top of the Interim queue (FIFO) once PRDs are reached within the Second Operational Tour. Officers may serve in the Second Operational Tour for periods greater than the prescribed tour length but never less.

D. MODEL CONSTRUCTS

Next, we introduce a widely accepted and convenient method for implementing the business rules (Career Path Dynamics) from the previous section. To capture the career dynamics described above, DES allows us to approach the problem in a modularized manner. If each operational assignment was thought of as a modular subassembly—each contributing a distinct behavior to the system, and also being a catalyst for events occurring in another module—DES provides a fitting method to model the career-path dynamics in a manner that systematically manages each event and the time the event occurs, while resolving any conflicts between any two or more events occurring at the same time. The following techniques provide one approach to implementing a DES model.

1. Event Graphs

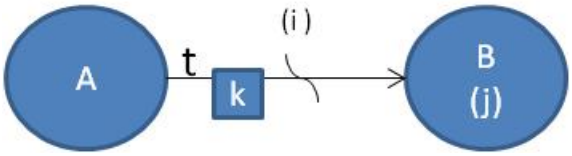
Event graphs were introduced by Schruben (1983) as a means of graphically representing DES models. For a comprehensive treatment of event graphs, see Schruben and Yücesan (1993).

A DES consists of two fundamental elements: (1) state variables, and (2) events. State variables maintain the information that determines the system's behavior. As

modelers, we need to track how these state variables change over time to yield the course of a simulation run. Events are instants in time where one or more state variable changes value. “The model simulates the system under study by producing state trajectories, which are time plots of the values of the system’s state variables. Measures of performance are determined as statistics of these state trajectories” (Buss, 1995, p. 74).

To paraphrase Buss (1995), each event graph consists of nodes and edges. Each node represents a distinct event or state transition, and each edge represents a scheduling relationship between a pair of events. Each edge has an associated time delay which must be a positive value, with zero being a valid possibility. Optionally, each edge may also have a Boolean condition or a set of values to be passed as parameters to the scheduled event. Figure 2 is interpreted as follows: Event A schedules event B to occur after a time delay of t if the Boolean condition (i) is true, passing value k to parameter j set to the value k. The value of k will be an argument or object to be acted upon in event B.

Figure 2. Basic Event Graph



Whenever Event A occurs, Event B is scheduled after time delay *t* if condition (*i*) is true, passing value k to parameter *j* to be operated on by Event B

2. Event List

Each DES framework requires an implementation of a Future Event List (FEL) to operate (Buss, 2001). The FEL is a priority queue of pending event notices in the simulation, and is ordered by the times at which the events will occur. An event gets scheduled to occur by adding an event notice and its associated event time to the FEL. An event can schedule more than one down-steam event. In such cases, each of the events is added to the FEL, prioritized by their event times.

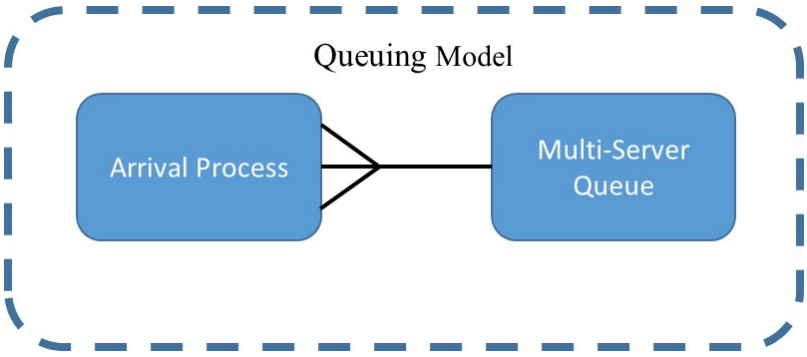
3. Listener Event Graph Objects

If we were to think of each operational assignment as a separate module, by extension, their implementations should be a set of separate and distinct sub-models, each characterized by its own set of behaviors. We need some way to connect the sub-models together. This is accomplished using Listener Event Graph Objects (LEGOs).

"LEGOs enable small models to be encapsulated in reusable modules. These modules are linked together using a design pattern from Object Oriented Programming, called the 'listener pattern,' to produce new modules of even greater complexity. The modules generated in this way can themselves be linked and encapsulated, forming a hierarchical design that is highly scalable" (Buss & Sanchez, 2002, p. 732).

Each sub-model may be connected by an event-listener pair, such that an event that occurs in one sub-model can trigger another event with the same signature in another sub-model. For example, an Arrival event in one sub-model causes an event with the same name to occur in another sub-model. An important distinction must be made here: if the causative event requires a parameter, the reactive event must do so as well. Within the Event Graph concept, two or more modules may be represented as an event-listener pair, as represented graphically in Figure 3.

Figure 3. Linking Model Components with Listeners



From Buss, A., & Sanchez, P. (2002). In Lee Schruben (Chair). Building complex models with LEGOS. *Proceedings of the 2002 Winter Simulation Conference*, Manchester Grand Hyatt San Diego, San Diego, CA. doi: http://informs-sim.org

Figure 3 is an introduction to the event-listener relationship using a new scheduling edge that resembles a trident. The sub-model that is adjacent to the three prongs is home to the causative event, with the other end of the trident being home to the reactive event.

4. Simkit

To simulate the behavior of the personnel assignment system, our DES model uses an open source Java library called Simkit developed by Arnold Buss, Ph.D., at the Naval Postgraduate School. The Simkit library provides a ready set of classes for implementation of DES models. The model for this thesis was implemented using a combination of built-in classes from Simkit, along with a set of new Java classes that were developed specifically for this model, to provide the desired behavior. Javadoc for Simkit classes can be found online at (http://diana.nps.edu/Simkit/doc/). It is assumed that readers have some familiarity with basic programming constructs and Java-based program development.

E. MODEL SUBSTRUCTURES

Describing the basic function of our model can be accomplished by imagining three separate containers representing the First Operational Tour, Interim Tour, and Second Operational Tour. Each container has a finite number of spots for a person to occupy. Once occupied, that person remains in that container until acted upon by an outside force, described further along in this subsection. Substructures of our model consist of the people themselves, objects that are acted upon, the containers, and a holding queue; each of which are described in detail in the following sections.

1. Entities

An officer entity can be thought of as an object with certain characteristics or attributes. As a Supply Corps officer transitions from one tour to another, their attributes or characteristics take on different values. Simkit offers an Entity class with built in variables for tracking pre-defined attributes or characteristics of a particular instance of

that Entity. Overriding this class, to include the constructor and various instance variables, provides the use of the Simkit Entity class with the desired behavior.

2. Data Structures

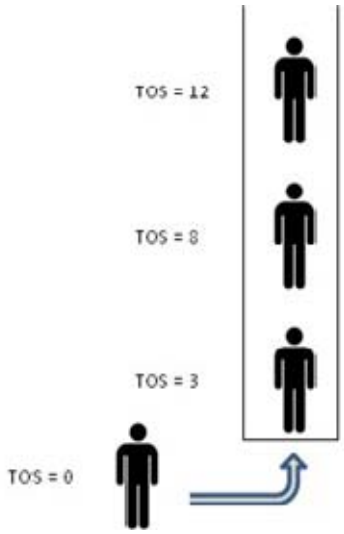
Once an officer or entity enters the simulation, its characteristics and attributes are set, but may be changed over the course of the simulation. Our simulation must store, in computer memory, each entity's attributes over the life of the simulation. We accomplish this for each operational assignment by using the existing Java linked-list class ordered by the officer's TOS. For each officer, TOS is computed at the end of their tour as they are being relieved, which is equal to the date the officer was relieved minus the date the officer reported. TOS is also computed, for ordering purposes only, for officers that are read in the database (discussed next). Note that computation of TOS for ordering purposes is not recorded for later analysis.

A Microsoft Access database was provided by PERS-4412 consisting of all Supply Corps officers on active duty belonging to and subject to assignment by PERS-4412. This database is used at run-time to pre-populate the operational assignment queues, as they exist in reality, at that instance in time. In practice, when we read in all the existing officers from the database, we must sort them by TOS within their corresponding queues (by operational assignment), to place the officer with the greatest TOS at the head of the queue, thereby ensuring that officer's transfer before all others within that operational assignment. Over the course of the simulation, the queues are on a first-in-first-out (FIFO) basis. This concept is further explained below.

Although the model consists of a handful of supporting modules and Java classes to implement the desired behavior, it is convenient to think of the model as consisting of three separate FIFO queues that represent each operational assignment. Figure 4 is a graphical depiction of the FIFO queue used in the simulation. At run-time, using Structured Query Language (SQL), our model sorts a single table of existing officers based on their current TOS into each respective operational assignment. This is accomplished by querying each record by the billet-type code (PERS-4412 currently differentiates billet types by shore duty and sea duty) and the current rank of the officer.

For example, an officer's record whose rank is found to be *Lieutenant* and billet type code *shore duty* is placed in the second operational assignment (Second Operational Tour) queue. The queue is sorted by TOS only after all records in the database have been examined by the query. Once the simulation is initialized (i.e., each officer is read in from the database), each successive officer that is created follows the FIFO behavior, as depicted in Figure 4.

Figure 4. FIFO Queue Sorted by Time on Station (TOS)



An artificially created officer is added to the tail of the pre-sorted queue

Once an officer progresses from one operational assignment to another (either the First Operational Tour node, Interim Tour node, or the Second Operational Tour node), the officer is added to the bottom of the queue corresponding to that job assignment.

3. Data

As mentioned in Chapter I, PERS-4412 uses Microsoft Access to store a snapshot of the current data reflected in the OAIS management information system. The development of our simulation model sought to utilize current tools already being used by PERS-4412 for manpower analysis. One requirement was to leave the existing data and analysis intact, while another was to simplify the end-user experience in using this simulation tool. The choice of Java as a development platform was largely based on its

free availability to anyone with an Internet connection, via the Java Development Kit for developers or the Java Run-time Environment for end-users.

Table 2 represents a typical, yet truncated, record found in the PERS-4412 database, which was utilized as a data source for our simulation. An explanation for each field name follows..

Table 2. Typical Record Found in PERS-4412 Microsoft Access Database

IRANK	INAME	IDESIG	IRECDDT	IPRD	IPEBD	ASNAME	AHPORT	BRANK	BDESIG	IPREVMILSVCMTH

Each field in Table 2 is described as follows:

- IRANK–current rank of the officer (not actively used in the simulation).
- INAME–name of the officer (not actively used in the simulation).
- IDESIG–4 digit designator of the officer.
- IRECDDT–date the officer was received at their current billet.
- IPRD–projected rotation date to be transferred to the next billet.
- IPEBD–pay entry base date; the date the officer entered service.
- ASNAME–activity name (i.e., billet holder) (not actively used in the simulation).
- AHPORT–activity home port (not actively used in the simulation).
- BRANK–required rank to fill a particular billet (not actively used in the simulation).
- BDESIG–required designator to fill a particular billet (not actively used in the simulation).
- IPREVMILSVCMTH–number of months of previous enlisted service (not actively used in the simulation).

a. JDBC

To facilitate communication from the simulation model to Microsoft Access, the pre-existing Java library JDBC was used in our development. The process of retrieving

data and storing it within our Java application requires loading the Access database driver, determining the location of the Access database, establishing a connection, building a query statement, and executing the query. Our model provides the end-user the option to specify the location of a more recent database for use in the simulation or by using an existing database packaged with the program by default, which was used in constructing the model. Building the query statement requires Structured Query Language (SQL), which is used in most mainstream commercial database applications.

b. SQL

Only a modest knowledge of the SQL programming language is necessary for understanding how our simulation executes queries to the PERS-4412 database. A brief introduction is provided for interested readers.

An SQL statement facilitates the retrieval of data from tables using table and field names as qualifiers and logical operators to produce the desired set of records. Our Java application uses the SELECT, FROM, WHERE, AND, OR, and '=' SQL syntax to form SQL statements. The following is an SQL example.

"SELECT IRANK, INAME, IDESIG, IRECDDT, IPRD,
IPEBD, ASNAME, AHPORT, BRANK, BDESIG,
IPREVMILSVCMTH FROM BILLET_BODIES WHERE

(IRANK = 'ENS' OR IRANK = 'LTJG') AND IPRD

<> '*' AND "(SSC = '2' OR SSC = '3' OR SSC =

'4' OR SSC = '8') AND IDESIG = '3100'"

- SELECT–which fields to select
- FROM–which table the data resides in
- WHERE–qualified conditions that must be met
- <>–logical "not equal to"
- OR–logical OR

- AND–logical AND

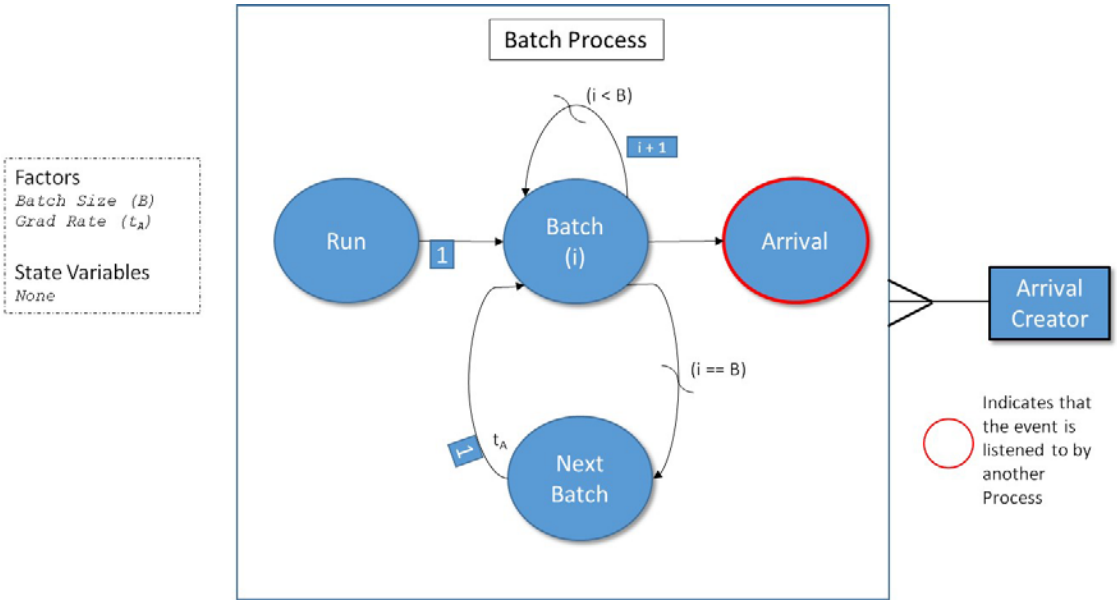
Field names must be separated by commas, and each qualifier enclosed in single quotes. The presence of parentheses provides that the enclosed portion of the statement gets executed separately. The entire SQL statement must be enclosed in double quotes.

4. Batch Process

Assignment to the Basic Qualification Course (BQC) is where a Supply Corps Officer's career begins, and where our model begins. The batch process module and underlying code seeks to emulate the act of convening a class of pre-determined size (Batch Size) arriving to the system at pre-determined intervals (Grad Rate). The majority of students who graduate the BQC expect to be immediately reassigned to an operational or sea-going billet. For the purposes of this analysis, this will be the standard assumption. The batch process module also accounts for the time between graduating classes with a built-in delay, which is also predetermined. The following paragraph describes the operation of the batch process in a more formal manner.

Officers arrive in batches of size B representing the new accessions to the Supply Corps by PERS-4412 (see Figure 5). The *Run* event triggers the arrival of the first cohort of officers by scheduling the *Batch(i)* event with an argument of 1. The *Batch(i)* event creates a new accession to attend Supply Corps School. Each new accession increments the value of *i* (an integer for counting, similar to the index in a 'for' loop) and if *i* is less than B it schedules another *Batch(i)* event with no time delay. This will result in a total of B accessions. Each execution of the Batch (i) event also schedules an *Arrival* event, which is intended to trigger a corresponding Arrival in the Arrival Creator module via the LEGO listener pattern. When the B^{th} batch has occurred (equal to the class size), the *Next Batch* event is scheduled immediately. The *Next Batch* event schedules a *Batch(i)* event with a delay of t_A (Grad Rate) and an argument of 1, repeating the overall batch arrival process. This process repeats indefinitely over the course of a simulation run, until the simulation is terminated.

Figure 5. Batch Process

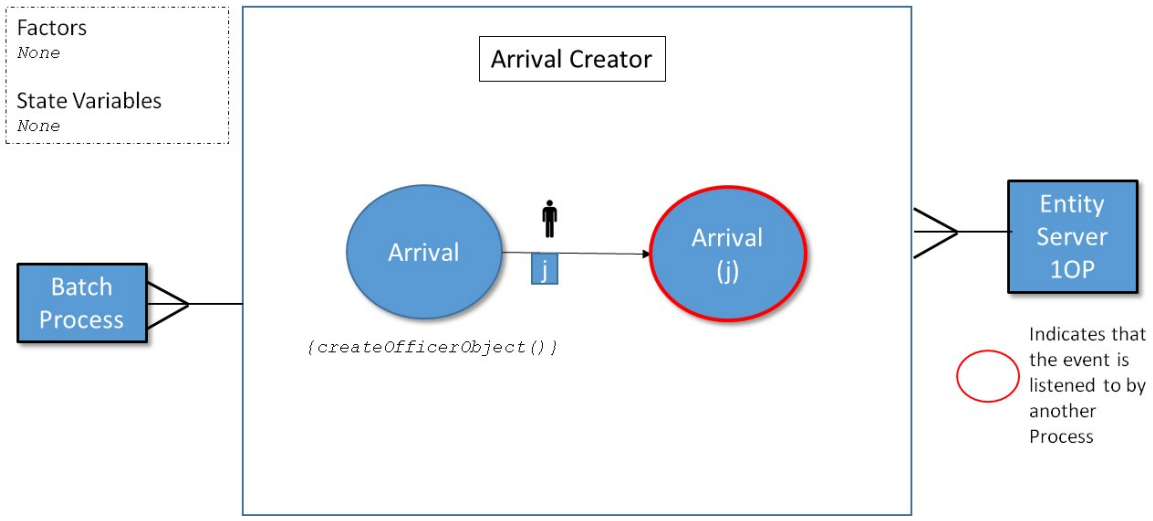


5. Arrival Creator

The primary role of the Arrival Creator module is to create officer objects for use in the simulation upon "hearing" each *Arrival* event from the Batch Process module. The underlying code creates an officer object and assigns it a standard set of attributes, as previously described in Table 2. This is implemented in the event graph as a simple method call to *createOfficerObject()*. The officer's pay entry based date (PEBD) is equal to system time plus the amount of simulated time that has lapsed. To clarify, the model uses the Java API Calendar class to retrieve the actual "real world" date and time (system time) and adds any time that has lapsed in the simulation (simulated time) to derive the date the officer arrived to the system. This date is used in calculating the officer's PRD downstream in the next module (EntityServer1OP). The Arrival Creator is best thought of as the mechanism that creates each new officer accession to the system and immediately assigns them to the first operational assignment (First Operational Tour). The following paragraph describes the operation of the Arrival Creator module in a more formal manner.

The Arrival Creator module instantiates a new officer object when it hears an *Arrival* event, and passes the officer along as an argument to the *Arrival(j)* event (see Figure 6. The *Arrival(j)* event is listened to by the Entity Server 1OP component.

Figure 6. Arrival Creator—a LEGO Implementation



6. Entity Server 1OP

The Entity Server 1OP module and underlying code seeks to simulate the assignment of officers to their first career assignment. For the newly assigned officer, this assignment entails the act of taking leave with duration determined by a random number, reporting and relieving the incumbent officer, and serving in that billet for the duration of time as prescribed by PERS-4412.

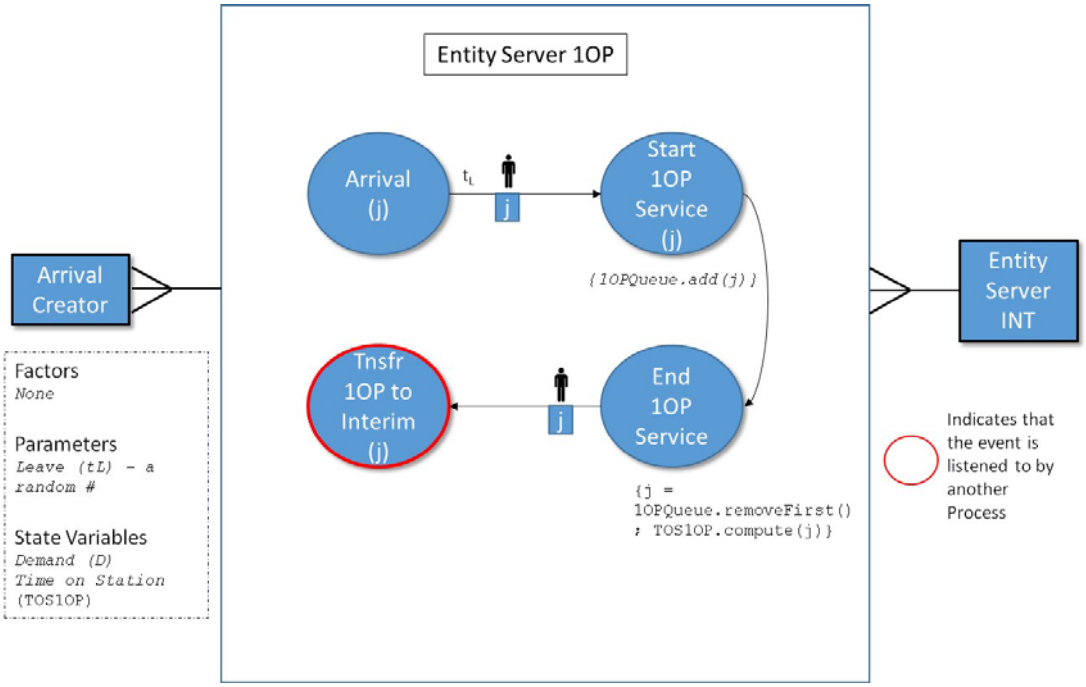
Unique to the entity server 1OP process is the determination of when an incumbent officer is relieved. An incumbent officer in the entity server 1OP process will not be relieved until a relief is made available, which has the effect of increasing the TOS of the incumbent officer if a relief is not immediately available. Alternatively, newly reporting reliefs displace incumbents within the First Operational Tour whether the incumbents have completed the prescribed duration of the tour or not. In simple terms, an arrival takes leave, triggers the *Start1OPService* event, and displaces an officer at the

head of the First Operational Tour queue, which then triggers the *End1OPService* event with the just-relieved officer being passed along as an argument

Common to all three operational assignments is the instantiation of a FIFO queue with officers already serving in that respective job assignment. The existing data are populated from an end-user database, as provided by PERS-4412. As part of the pre-population of the FIFO queues at run-time, the Entity Server 1OP module also has an explicit process by which each existing officer, already assigned to a First Operational Tour, is assigned a rotation date based on their existing PRDs. This process occurs before any personnel transfers between operational assignments are made. The following paragraph more formally describes the operation of the entity server 1OP process.

An *Arrival(j)* event from the Arrival Creator is heard by the *Arrival(j)* event, which schedules the *Start 1OP Service(j)* event with the generated officer object as an argument and a delay of t_L (Leave) (see Figure 7). After the amount of leave the officer elects to take (determined by a random number) has elapsed, the officer is added to the tail of the First Operational Tour queue. Once added to the queue, the officer remains in their First Operational Tour until a relieving officer arrives after the required time in the billet. Each new arrival directly translates into one officer being relieved of their First Operational Tour, which is executed by the *End 1OP Service* event. The *End 1OP Service* event removes the officer at the head of the First Operational Tour queue, computes the time that officer served in their First Operational Tour, and passes the officer along as an argument to the *Transfer 1OP to Interim(j)* event.

Figure 7. Entity Server 1OP



7. Entity Server INT

The Entity Server INT process and underlying code seeks to simulate the assignment of officers to their second career assignment. Like the other two tours, the Interim Tour has a nominal maximum number of 364 funded billets. Unique to this module, however, is the ability to accept incoming transfers or reliefs in excess of the nominal 364 billets. By comparison, the other tours' incumbents are exchanged with reliefs on a 1:1 ratio and their queues do not increase or decrease in size. No preference is provided for having a condition where the queue size is consistently less than or greater than the 364 funded billet limit.

For the newly assigned officer, this assignment entails the act of taking leave (duration determined by a random number), reporting and relieving the incumbent officer, and serving in that billet for the duration of time prescribed by PERS-4412. As part of the pre-population of the FIFO queues at run-time, the Entity Server INT module also has an explicit process by which each existing officer, already assigned to an Interim Tour, is assigned a rotation date based on their existing PRDs—a process that occurs

before any personnel transfers between billets are made. In simple terms, the Entity Server INT process rotates incoming personnel who are reporting to the interim operational assignment by placing the reporting officer in that billet where the incumbent has the greatest TOS. The incumbent officer who has the greatest TOS will be at the head of this module's queue based on the model's FIFO nature. The incumbent who has just been relieved is then either assigned to another interim career billet and placed at the tail of the queue or assigned to a Second Operational Tour billet if the demand signal coming from the Second Operational Tour module is greater than zero. The following paragraph formally describes the operation of the entity server INT process

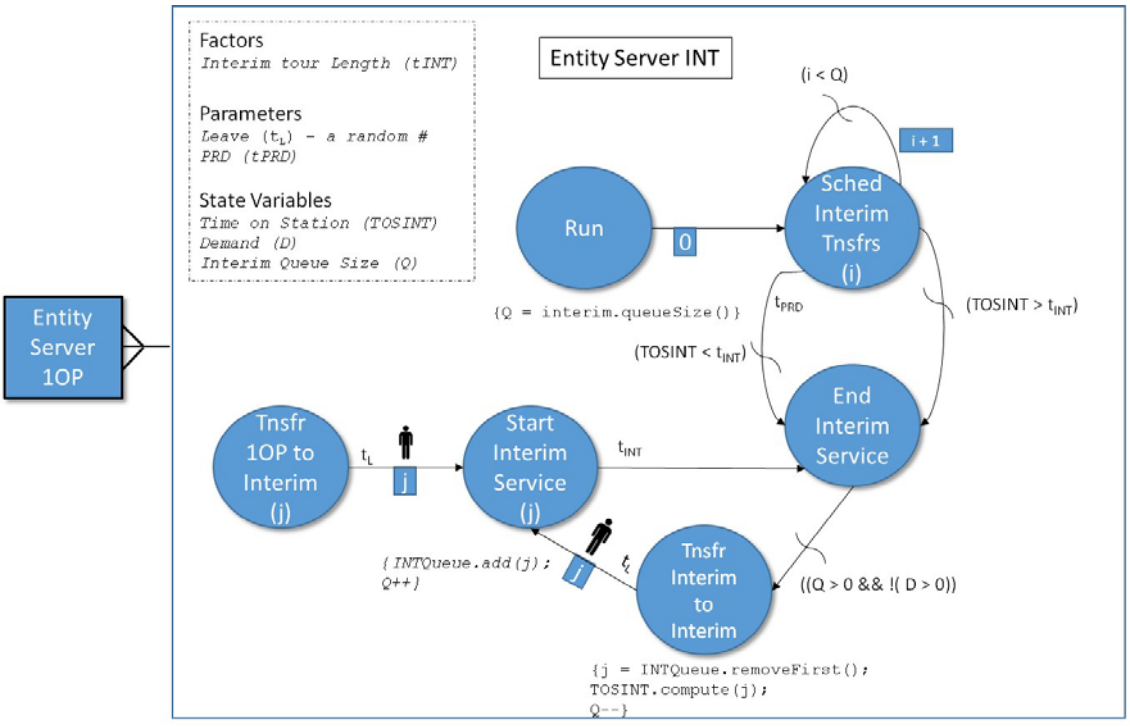
At run time the *Run* event is executed, scheduling the *Schedule Interim Transfers(i)* event with an argument of 0 (see Figure 8). The *Schedule Interim Transfers(i)* event, in practice, reads each officer in from the end-user database and schedules an *End Interim Service* event with a delay based on each respective officer's current TOS. If an officer has a greater TOS than that prescribed by the user at run time, then that officer is immediately reassigned using the *End Interim Service* event. Otherwise, the *End Interim Service* event is scheduled with a delay of t_{PRD} or the computed time that the officer has left to serve in that Interim Tour. In other words, if TOS is less than the prescribed Interim Tour length, the officer will remain in the Interim Tour queue and the respective *End Interim Service* event will be scheduled with a delay of t_{PRD}. The *Schedule Interim Transfers (i)* event continues to reschedule itself immediately until the value of *i* (an integer for counting, similar to the index in a 'for' loop) is one less the size of the Interim Tour queue.

An officer removed from the Interim Tour queue, after the End Interim Service event is executed, will be assigned to either another Interim Tour, or to a Second Operational Tour. If the demand signal D for a Second Operational Tour is greater than zero, the officer will be immediately assigned to a Second Operational Tour by scheduling the Transfer Interim to 2OP event. Otherwise, the officer is reassigned to another Interim Tour by scheduling the Transfer Interim to Interim event with no delay. The Transfer Interim to 2OP event is listened to by the Entity Server 2OP Pull module. The *Transfer Interim to Interim* event removes the officer at the head of the Interim Tour

queue, computes the TOS during that Interim Tour, and schedules a *Start Interim Service(j)* event for that officer after a delay of t_L (leave). After the officer's leave elapses, the *Start Interim Service(j)* event adds the officer to the tail of the Interim Tour queue and schedules an *End Interim Service* event with a delay equal to the prescribed Interim Tour length (t_{INT})

After hearing a *Transfer 1OP to Interim(j)* event from the *Entity Server 1OP* module, an event with the same signature and name is executed within the *Entity Server INT* module. The *Transfer 1OP to Interim(j)* event accepts the officer removed from the *Entity Server 1OP* module as an argument, increments the state variable *Q* (size of the interim queue) by one, and schedules the *Start Interim Service(j)* event for that officer with a delay of t_L. The *Start Interim Service(j)* is executed in the same manner as described in the previous paragraph.

Figure 8. Entity Server INT



8. Entity Server 2OP

The entity server 2OP module and underlying code seeks to simulate the assignment of officers to their Second Operational Tour. For the newly assigned officer, this assignment entails the act of taking leave, reporting, and relieving the incumbent officer, and serving in that billet for the entire duration of time, as prescribed by PERS-4412. The entity server 2OP module also has an explicit process by which each existing officer, already assigned to a Second Operational Tour, is assigned a rotation date based on their existing PRDs. This occurs before any personnel transfers between billets are made. The entity server 2OP module rotates incoming personnel who are reporting to the Second Operational Tour by placing the reporting officer in a billet where the incumbent has the greatest time on station TOS. The incumbent officer who has the greatest TOS will be at the head of this module's queue based on the model's FIFO nature. The incumbent from the Second Operational Tour queue who has just been relieved is permanently removed from the queue and the simulation only after collection of the desired metrics—namely the length of the Second Operational Tour for that officer instance. The following paragraph formally describes the operation of the entity server 2OP process.

As shown in Figure 9, at run time the *Run* event schedules the *Schedule 2OP Transfers(i)* event with an argument of 0. The *Schedule 2OP Transfers(i)* event, in practice, reads in each officer from the end-user database, stores them in the Second Operational Tour queue, and schedules an *End 2OP Service* event with a delay based on each respective officer's current TOS. If an officer has a greater TOS than that prescribed by the user at run time, that officer is immediately reassigned by scheduling an *End 2OP Service* event with no delay. Otherwise, the *End 2OP Service* event is scheduled with a delay of t_{PRD}—the computed time that officer has left to serve in that Second Operational Tour. If TOS is less than the Prescribed Second Operational Tour length, the officer will remain in the Second Operational Tour queue and the respective *End Interim Service* event will be scheduled with a delay of t_{PRD}. The *Schedule 2OP Transfers(i)* event continues to reschedule itself immediately until the value of *i* (an integer for counting,

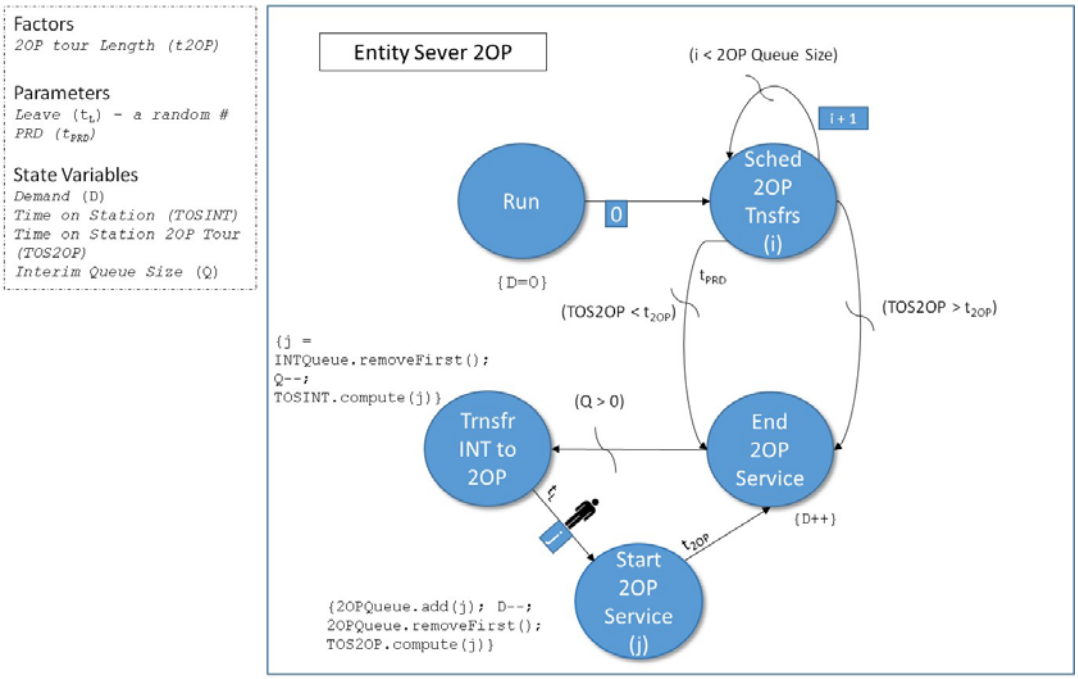
similar to the index in a ‘for’ loop) is one less the size of the Second Operational Tour queue.

An officer removed from the Second Operational Tour queue after the End 2OP Service is executed will increment the demand signal D by one and schedule a *Transfer Interim to 2OP* event without delay if, the Interim Tour queue actually has an officer in it to transfer. It is important to point out here that the requirement to meet the Boolean condition *INTQueueSize > 0* is only implemented to keep the program from experiencing a null pointer exception—in practice, a community manager would never seek such an imbalance that the demands in the Second Operational Tour outpace the source of supply. The demand signal D keeps the prioritization of the Second Operational Tour intact.

Execution of the *Transfer Interim to 2OP* event removes an officer from the top of the Second Operational Tour queue (FIFO), decrements the value of Q (interim queue size) by one, computes the TOS—the total time served in a billet— for both the officer removed from the Interim Tour and the officer relieved from the Second Operational Tour, and decrements the demand signal D. The *Transfer Interim to 2OP* event then schedules the *Start 2OP Service(j)* event, passing along the officer removed from the Interim Tour queue as an argument with a delay equal to amount of leave elected by that officer. The *Transfer Interim to 2OP* event also executes when another event with the same signature is heard from the Entity Server INT component.

The *Start 2OP Service(j)* event adds the officer received as an argument and schedules an *End 2OP Service* event with a delay equal to the amount time an officer serves in their Second Operational Tour—prescribed at run time.

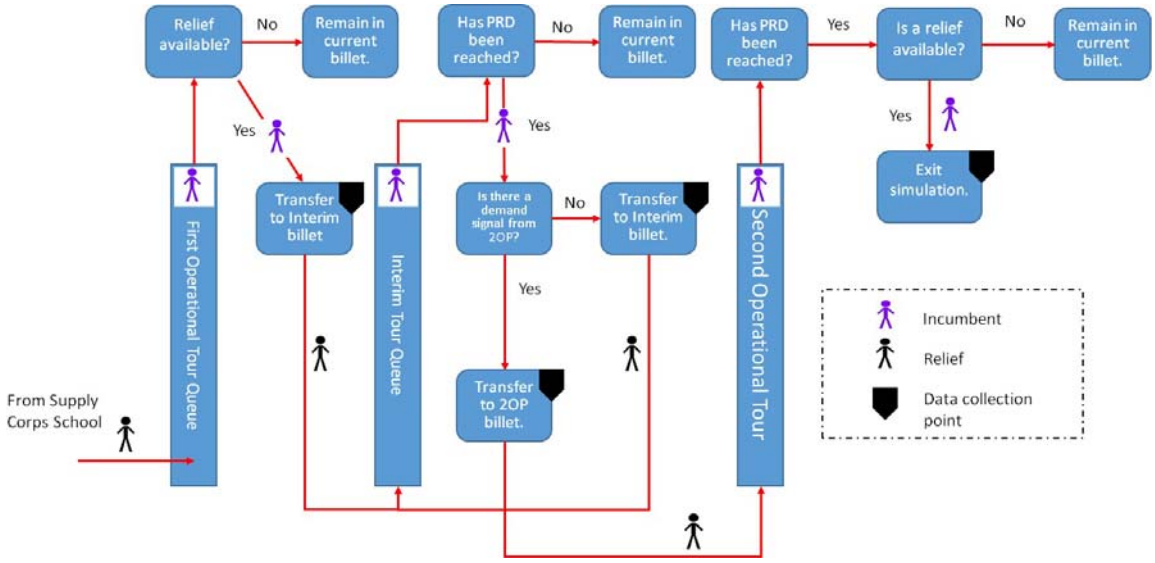
Figure 9. Entity Server 2OP



9. Inter-module Interaction

The diagram in Figure 10 is a succinct and logical account of the operation of the underlying model. It is important to note that an incumbent officer in the First Operational Tour queue, represented by the left-most blue columnar shape, does not transfer to the next operational assignment until a relief is provided from the Supply Corps School. This will have a profound impact on the length of the First Operational Tour, which in turn is based on the factors Grad Rate and Batch Size. Additionally, Figure 10 uses shield shapes to represent points of data collection, namely the length of each respective tour incurred by that officer. Upon data collection, that officer has now taken on the role of a relieving officer.

Figure 10. Module Interaction Summary



Another possible point of confusion, which we will attempt to clarify, lies within the Second Operational Tour module. Once the demand flag or signal is set, this indicates invariably that an incumbent officer within the Second Operational Tour queue has reached their PRD. If no immediate relief is available, the incumbent must remain in queue until a relief is identified downstream in the other two operational assignments. The deficit only occurs when there are no new accessions to the system and insufficient reliefs are available from Interim Tours, resulting in the queue being empty. Where there are sufficient levels of personnel available from Interim Tours—personnel numbering greater than zero—a personnel transfer from the Interim Tour to the Second Operational Tour is affected immediately, potentially cutting short that Interim Tour officer's TOS.

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III. PREPARATION FOR ANALYSIS

A. FORMULATING RESEARCH QUESTIONS

The following questions were posed by PERS-4412.

"**What should the tour lengths be for each officer in their successive assignments to a First Operational, Interim, and Second Operational Tour?**"

This needs to be translated to operational terms by positing a relationship between factors under our control, represented as simulation inputs, and the corresponding tour lengths that are observed. This leads us to re-express the question by defining quantifiable measures and their relationships to the factor settings.

How does each of the factors affect each of the tour lengths?

For tour lengths, our model collects data on each officer's actual tour length with the goal of statistically determining the causal relationships of the factors.

Given the limited number of billets authorized for shore duty, which factors provide for the greatest amount of control over the expansion and contraction of the Interim tour queue?

Since the Interim Queue acts as a buffer, our model collects data on the overall queue size each time it changes. The amount of funded billets for officers entering their Interim Tour is fixed at 364 (at the time of this writing).

Are there policy choices that can improve unmet demand performance?

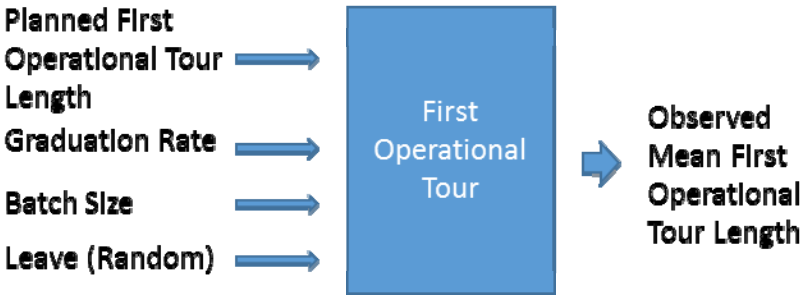
Our model also collects values for the global variable "Unmet Demand." Each time an incumbent officer is not able to be relieved due to an upstream relief being unavailable, the value of Unmet Demand is incremented by (1), and conversely, decremented by (1) when the demand is finally met.

1. First Operational Tour Inputs/Outputs

To address the questions posed above, we need to specify inputs that are controllable in the real-world system, and measureable outputs that capture the desired

characteristics and behaviors of that system. The inputs and outputs for the First Operational Tour are shown in Figure 11.

Figure 11. Inputs/Outputs—First Operational Tour



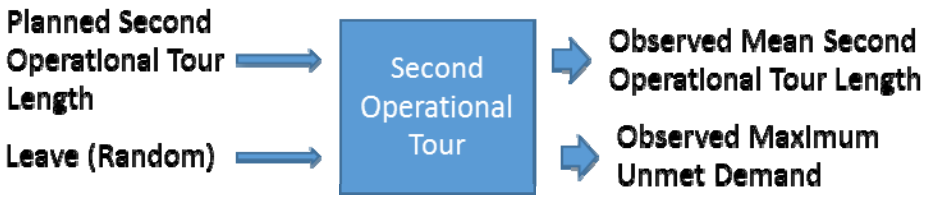
Note that although our model allows for the nominal specification of the First Operational Tour length as a factor, hereafter referred to as the Prescribed First Operational Tour Length, the resultant duration is not a result of user-controlled input, and therefore not an independent variable (input), but rather a dependent variable (an output). As an output, the Mean First Operational Tour Length is hereafter referred to as the Observed Mean First Operational Tour Length. With respect to inputs and outputs, the remaining two tours are characterized in this same manner.

2. Second Operational Tour Inputs/Outputs

The last stop for officers in our simulation is the Second Operational Tour. Figure 12 depicts the inputs and outputs for the Second Operational Tour. Since no external demands are placed on this tour, both incumbents and future reliefs can be expected to serve in this tour for the prescribed amount of time. This is known simply as the Prescribed Second Operational Tour Length, and is an independent variable under full control by PERS-4412. Once an officer completes their tour and reaches PRD a demand is placed on the system. This demand is filled first by incumbents within the Interim Tour. The only instance where an incumbent will not transfer at their prescribed PRD is when an upstream relief is not available. An incumbent whose time has matured past PRD is relieved when the next relief becomes available.

For our analysis, we are interested in the Observed Mean Second Operational Tour Length, and the maximum number of unmet demands (dependent variable) experienced by the system. The Prescribed Second Operational Tour length is prescribed at run-time, and the resultant or Observed Mean Second Operational Tour Length is affected by unmet demands and the amount of leave taken by the relieving officer (as displayed in Figure 12). Maximum Unmet Demand is the maximum value realized over the course of a simulation replication.

Figure 12. Inputs/Outputs—Second Operational Tour


Planned Second Operational Tour Length
Leave (Random)
Second Operational Tour
Observed Mean Second Operational Tour Length
Observed Maximum Unmet Demand

3. Interim Tour Inputs/Outputs

The primary focus of our analysis is on the Interim Tour, since the Observed First Operational Tour length is primarily a function of the inputs Batch Size and Grad Rate and the Observed Second Operational Tour length is grossly unaffected by events upstream (for a stable system), except in those rare cases when the demand signal cannot immediately be satisfied.

The Interim Tour acts as a buffer growing and contracting as new accessions are added or PRDs within the Interim Tour are reached. The Prescribed Interim Tour Length is prescribed at run-time. Like the two previous tours, we are again interested in the Observed Mean Interim Tour Length, as well as the Observed Mean Interim Queue Size as measures of performance. Reacting to events down- and upstream, the resultant outputs are shown in Figure 13.

Figure 13. Inputs/Outputs—Interim Tour

Inputs to our model and the outputs we wish to study are summarized in Figure 14. A summary of inputs and outputs is provided in Table 3.

Figure 14. Graphical Summary of Model Inputs and Outputs

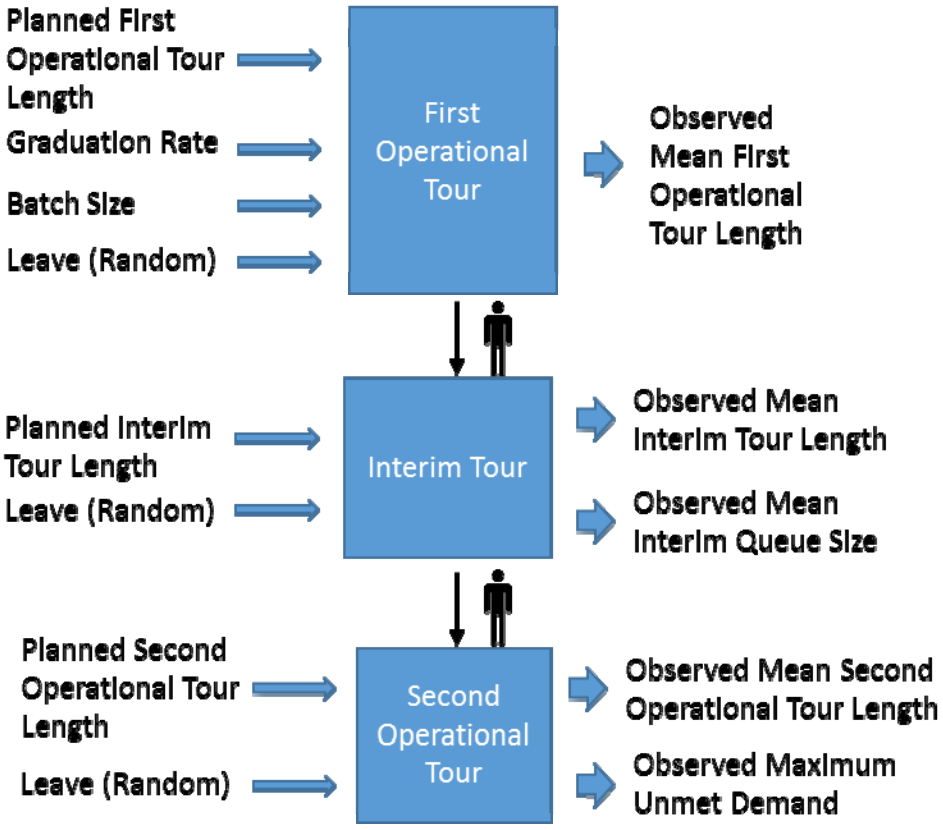


Table 3. Summary of Inputs and Outputs

Input/Output	Run Parameter (Name / ID)	Summary	Lower Limit (Unit)	Upper Limit (Unit)
Input	Batch Size **(B)**	Size of graduating class from Basic Qualification Course (BQC)	15 (Students)	37 (Students)
Input	Grad Rate **(t_A)**	Frequency of a batch (graduating class)	2.0 (Months)	3.0 (Months)
Input	Prescribed First Operational Tour Length **(t_{1OP})**	Total time each officer is expected to spend at their First Operational Tour.	24.0 (Months)	60.0 (Months)
Input	Prescribed Interim Tour Length **(t_{INT})**	Total time each officer is expected to spend at their Interim Tour	12.0 (Months)	48.0 (Months)
Input	Prescribed Second Operational Tour Length **(t_{2OP})**	Total time each officer is expected to spend at their Second Operational Tour	18.0 (Months)	48.0 (Months)
Output	Observed Mean First Operational Tour Length **(TOS_{1OP})**	- Collected data consists of completed First Operational Tours only which are averaged at the end of each simulation replication to obtain the output	N/A	N/A
Output	Observed Mean Interim Tour Length **(TOS_{INT})**	- Collected data consists of completed Interim Tours only which are averaged at the end of each simulation replication to obtain the output	N/A	N/A
Output	Observed Mean Second Operational Tour Length **(TOS_{2OP})**	- Collected data consists of completed Second Operational Tours only which are averaged at the end of each simulation replication to obtain the output	N/A	N/A
Output	Observed Maximum Unmet Demand (**D**)	- Collected data consists of the magnitude of Unmet Demand which is recorded each time there is a change to the demand signal. The maximum is then taken at the end of each simulation replication to obtain the output	N/A	N/A
Output	Observed Mean Interim Queue Size **(Q)**	- Collected data consists of the magnitude of the Interim Queue Size which is recorded each time there is a change to the Interim Queue Size. The data is then averaged at the end of each simulation replication to obtain the output	N/A	N/A

4. Measures of Effectiveness

Quantitative analysis requires us to specify one or more MOEs. We intend to investigate policy effects on our model by varying inputs to represent possible interventions under consideration by PERS-4412, and observing the outcomes or effects of those changes. Using MOEs to judge the impact of various policy changes will allow us to move closer to a recommendation(s) that meets or exceeds our sponsor's goals. Table 4 describes the MOEs chosen for analysis.

Table 4. Summary of MOEs

MOE	Description	Criterion	Computation Method
Tour Length	1. Observed Mean 1OP Tour Length 2. Observed Mean Interim Tour Length 3. Observed Mean 2OP Tour Length	Minimize difference between observed means and prescribed tour lengths	Mean Tour Length is minimized through use of the metamodel profiler (See chapter 4, subsection 6)
Interim Queue Size	Observed Mean Interim Queue Size	Minimize the growth and contraction of the Interim Queue Size about the maximum number of funded billets of 364	The absolute difference between the Mean Interim Queue Size and maximum number of funded billets (364) is minimized through use of the metamodel profiler (See chapter IV, subsection 6)
Unmet demand	Observed Mean Maximum Unmet Demand	Minimize Mean Maximum Unmet Demand	Mean Maximum Unmet Demand is minimized through use of the metamodel profiler (See chapter IV, subsection 6)

5. Maximum Unmet Demand versus Mean Maximum Unmet Demand

To explain what Mean Maximum Unmet Demand is and how it is derived, we first start with the raw data that is collected from the simulation model, Unmet Demand. As you may recall, an Unmet Demand occurs whenever a Second Operational Tour incumbent reaches PRD and is ready to be relieved—the demand counter is incremented by (1) and its magnitude recorded for later analysis. The demand counter is decremented by (1) once a relief reports from the Interim queue—also recorded for later analysis.

The maximum of Unmet Demand is the largest value realized for Unmet Demand across a simulation replication. Mean Maximum Unmet Demand is what we wish to minimize by use of a metamodel—discussed next and in depth in Chapter IV.

To clarify how Mean Maximum Unmet Demand is derived, we took the maximum of Unmet Demand across 100 replications for each of the 33 design points. With a dataset consisting of 3300 averages, we summarized the data, by group—factor level settings—in order to obtain the Mean Maximum Unmet Demand for each of the 33 design points. It was this 33-observation dataset that was used in metamodel construction.

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IV. ANALYSIS AND RESULTS

A. ANALYSIS METHODOLOGY

An essential first step in the analysis is to choose an appropriate analysis methodology. Using the decision tree from Sanchez (2007), we have classified the model as stochastic and terminating. This means that performance measures will be summarized at the end of each replication, and we will use replicated runs to obtain suitable sample sizes. Since the Department of Defense and U.S. Navy do not use infinite planning horizons, we have elected to limit the duration of each replication to ten years.

B. DESIGN OF EXPERIMENTS

In exploring the behavior or relationship between several inputs (factors) and the output(s) (responses), the total number of experiments required can quickly become overwhelming if approached incorrectly. In order to efficiently explore our simulation, a Nearly Orthogonal Latin Hyper-Cube (NOLH) design was utilized. A design is specified in tabular form, where the columns are factors and the rows are design points, which specify the factor settings for a particular configuration to be run one or more times (i.e., replicated). The particular design chosen has 33 design points, and can accommodate up to 11 factors—more than sufficient for our experiments with five factors. It is presented in Figure 15, where B = Batch Size, T_A = Graduation Rate, T_1OP = Prescribed First Operational Tour Length, T_INT = Prescribed Interim Tour Length, and T_2OP = Prescribed Second Operational Tour Length.

Figure 15. NOLH Design—Five Factors and 33 Design Points

low level	15	2	24	12	18
high level	37	3	60	48	48
decimals	0	4	0	0	0
factor name	B	T_A	T_1OP	T_INT	T_2OP
	37	2.0938	40	19	44
	35	3	29	26	32
	34	2.4375	57	18	19
	27	2.875	60	27	46
	36	2.0313	41	20	39
	36	2.9375	35	22	31
	30	2.4688	59	21	18
	27	2.6875	58	24	45
	29	2.25	32	31	40
	32	2.6563	34	37	25
	31	2.2188	51	47	28
	32	2.7188	48	46	41
	28	2.1563	31	32	36
	34	2.5938	38	44	23
	29	2.1875	54	45	29
	33	2.625	45	48	42
	26	2.5	42	30	33
	15	2.9063	44	41	22
	17	2	56	35	34
	18	2.5625	27	42	47
	25	2.125	24	33	20
	16	2.9688	43	40	27
	16	2.0625	49	38	35
	22	2.5313	25	39	48
	25	2.3125	26	36	21
	23	2.75	52	29	26
	21	2.3438	50	23	41
	21	2.7813	33	13	38
	20	2.2813	36	14	26
	24	2.8438	53	28	30
	18	2.4063	47	17	43
	23	2.8125	30	15	37
	19	2.375	39	12	24

C. REPLICATION

We elected to perform 100 replications for each design point, yielding 3300 simulated experiments. From every simulation replication, data is collected about the time each officer, passing through the sequence of tours, spends in each tour over a period of ten years. Data on Interim Queue Size and Unmet Demand is also collected where the size of the Interim queue and the magnitude of Unmet Demand are recorded each time they change in value. The Mean is then calculated from each data output

stream for analysis. Data for officers still in the queue at the end of a simulation replication were are not collected.

D. ANALYSIS OF OUTPUTS

In order to address our research questions, we have elected to build metamodels for each of the MOEs, based on our simulation model's output. Each model quantifies the effect(s) of each of the five factors on a given MOE. The statistical software suite JMP Pro 12 was used in the development of all our models.

E. METAMODEL CONSTRUCTION

Using linear regression, we can derive relationships between factor settings and observed outcomes. We have used stepwise regression to summarize each mean tour length across each set of 100 runs over 33 design points grouped by factor levels, which focuses the analysis on mean performance of the MOEs. The stepwise regression bases initial factor selection on Akaike's Information Criterion (AIC).

We will begin our discussion with the model for Mean First Operational Tour Lengths. This is followed by models for each of the remaining career job assignments, along with the interim queue size, and we conclude with a composite model that allows us to investigate the effect of policy changes on all MOEs simultaneously.

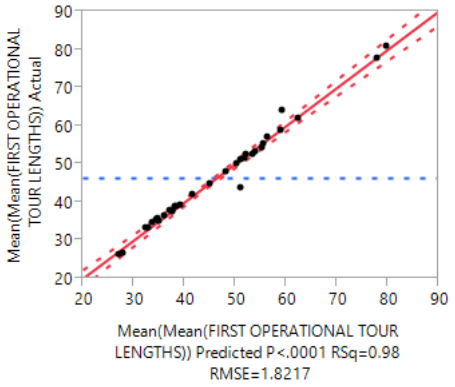
1. Mean First Operational Tour Length

Our first regression model was constructed with all five factors as the input variables and the Observed Mean First Operational Tour Length as the dependent variable. The summary statistics indicate a very good predictive capability, with an adjusted R^2 value of 0.9807. Parameter estimates for each of the coefficients are displayed in Figure 16 for the final stepwise regression, along with full diagnostic reports.

Figure 16. Model—Mean 1OP Tour Length

Response Mean(Mean(FIRST OPERATIONAL TOUR LENGTHS))

Actual by Predicted Plot



Summary of Fit

RSquare	0.983082
RSquare Adj	0.980666
Root Mean Square Error	1.821735
Mean of Response	46.26952
Observations (or Sum Wgts)	33

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	5399.8120	1349.95	406.7696
Error	28	92.9241	3.32	Prob > F
C. Total	32	5492.7360		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	43.496633	2.983418	14.58	<.0001*
B	-1.718606	0.048127	-35.71	<.0001*
T_A	17.805228	1.065905	16.70	<.0001*
(B-25.9091)*(T_A-2.50002)	-0.615773	0.136621	-4.51	0.0001*
(B-25.9091)*(B-25.9091)	0.0637308	0.008351	7.63	<.0001*

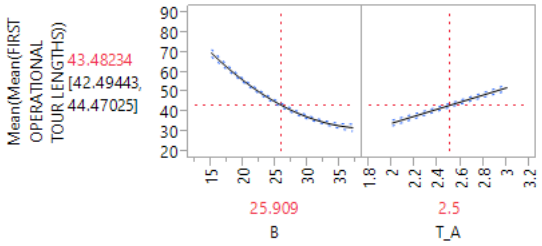
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
B	1	1	4232.0560	1275.209	<.0001*
T_A	1	1	926.0364	279.0345	<.0001*
B*T_A	1	1	67.4184	20.3146	0.0001*
B*B	1	1	193.2996	58.2453	<.0001*

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
B	-1.718606	0.048127	-35.71	<.0001*
T_A	17.805228	1.065905	16.70	<.0001*
(B-25.9091)*(B-25.9091)	0.0637308	0.008351	7.63	<.0001*
(B-25.9091)*(T_A-2.50002)	-0.615773	0.136621	-4.51	0.0001*

Prediction Profiler



Note that only two of our five factors have any impact on the Mean 1OP Tour Length. Parameter estimates for the three excluded input factors are not reflected in the model due to their statistical insignificance. The dominant factor is the Batch Size B—as batch sizes increase, the tour lengths will decrease. However, the presence of a quadratic term in B indicates diminishing returns to scale for this effect. The graduation rate t_A is also significant, and has a positive slope—as the graduation rate increases, the average length of the first operational tour increases proportionally. Finally, there is an interaction between the two factors—changes to either factor affect the magnitude of the impact of the other factor on the Mean 1OP Tour Length.

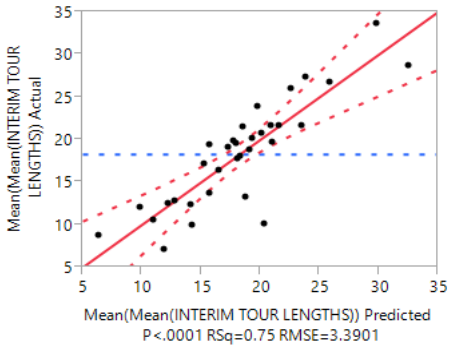
2. Mean Interim Tour Length

Our next model was constructed with all five factors as the input variables and the Observed Mean Interim Tour Length as the dependent variable. The model's summary statistics indicate less predictive power than our first model, with an adjusted R^2 value of 0.7066. Parameter estimates for each of the coefficients for the final stepwise regression are displayed in Figure 17, along with full diagnostics.

Figure 17. Model—Mean INT Tour Length

Response Mean(Mean(INTERIM TOUR LENGTHS))

Actual by Predicted Plot



Summary of Fit

RSquare	0.752437
RSquare Adj	0.706592
Root Mean Square Error	3.390101
Mean of Response	18.25998
Observations (or Sum Wgts)	33

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	943.1347	188.627	16.4126
Error	27	310.3052	11.493	Prob > F
C. Total	32	1253.4399		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	11.906471	3.660547	3.25	0.0031*
B	-0.112105	0.08948	-1.25	0.2210
INT	0.27635	0.054921	5.03	<.0001*
2OP	0.0318692	0.066615	0.48	0.6362
(B-25.9091)*(2OP-33.0303)	0.0644884	0.010808	5.97	<.0001*
(INT-30.0606)*(2OP-33.0303)	0.0345555	0.006402	5.40	<.0001*

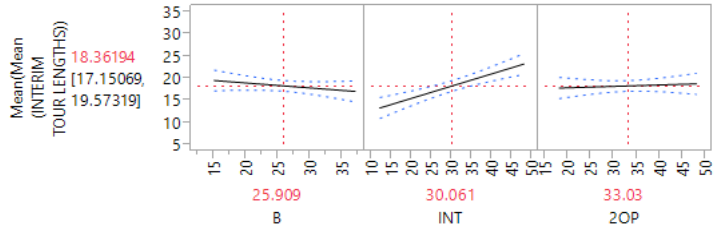
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
B	1	1	18.03925	1.5696	0.2210
INT	1	1	290.98216	25.3187	<.0001*
2OP	1	1	2.63038	0.2289	0.6362
B*2OP	1	1	409.17193	35.6025	<.0001*
INT*2OP	1	1	334.86665	29.1371	<.0001*

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
(B-25.9091)*(2OP-33.0303)	0.0644884	0.010808	5.97	<.0001*
(INT-30.0606)*(2OP-33.0303)	0.0345555	0.006402	5.40	<.0001*
INT	0.27635	0.054921	5.03	<.0001*
B	-0.112105	0.08948	-1.25	0.2210
2OP	0.0318692	0.066615	0.48	0.6362

Prediction Profiler



Note that three of our five factors influence the Observed Mean Interim Tour Length. Parameter estimates for the two excluded input factors are not reflected in the model due to their statistical insignificance. We also have notable differences from the first model, because the interactions among the factors are more significant than the main effects.

The interactions between Batch Size B and the Prescribed Second Operational Tour Length, and Prescribed Interim Tour Length INT and the Prescribed Second Operational Tour Length, are the most significant. A change in any of these factors affects the magnitude of the impact the paired factor has on the Observed Mean Interim Tour Length.

INT is the next significant term, with a strong positive slope. Any change in the Prescribed Interim Tour Length has a proportional effect on Observed Mean Interim Tour Length.

Finally, the main effects for factors B and 2OP are statistically insignificant (i.e., they cannot be distinguished from zero effect). Both factors are retained in the model to preserve hierarchy, since they are used in higher-order terms.

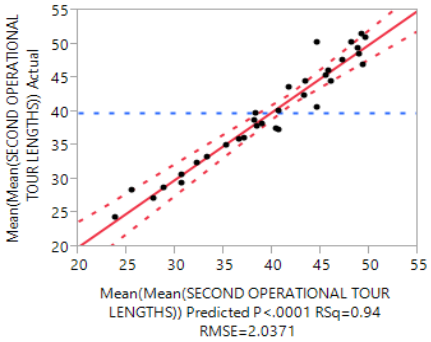
3. Mean Second Operational Tour Length

A regression model with all five factors as the input variables and the Observed Mean Second Operational Tour Length as the dependent variable has good predictive power, yielding an adjusted R^2 value of *0.9301*. Parameter estimates for each of the coefficients for the final stepwise regression are displayed in Figure 18. Note that parameter estimates for the two excluded input factors are not reflected in the model due to their statistical insignificance.

Figure 18. Model—Mean 2OP Tour Length

Response Mean(Mean(SECOND OPERATIONAL TOUR LENGTHS))

Actual by Predicted Plot



Summary of Fit

RSquare	0.943179
RSquare Adj	0.930067
Root Mean Square Error	2.037061
Mean of Response	39.80849
Observations (or Sum Wgts)	33

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	1790.8866	298.481	71.9298
Error	26	107.8901	4.150	Prob > F
C. Total	32	1898.7767		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	12.988652	3.596334	3.61	0.0013*
B	-0.409444	0.053838	-7.61	<.0001*
T_A	6.184914	1.191925	5.19	<.0001*
2OP	0.6296511	0.040032	15.73	<.0001*
(B-25.9091)*(T_A-2.50002)	-0.600931	0.165644	-3.63	0.0012*
(B-25.9091)*(2OP-33.0303	0.0384947	0.007145	5.39	<.0001*
(B-25.9091)*(B-25.9091)	0.0276794	0.009596	2.88	0.0078*

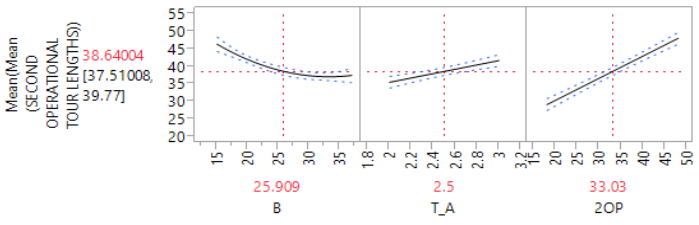
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
B	1	1	240.0083	57.8387	<.0001*
T_A	1	1	111.7320	26.9258	<.0001*
2OP	1	1	1026.5666	247.3882	<.0001*
B*T_A	1	1	54.6146	13.1613	0.0012*
B*2OP	1	1	120.4425	29.0250	<.0001*
B*B	1	1	34.5281	8.3208	0.0078*

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
2OP	0.6296511	0.040032	15.73	<.0001*
B	-0.409444	0.053838	-7.61	<.0001*
(B-25.9091)*(2OP-33.0303	0.0384947	0.007145	5.39	<.0001*
T_A	6.184914	1.191925	5.19	<.0001*
(B-25.9091)*(T_A-2.50002)	-0.600931	0.165644	-3.63	0.0012*
(B-25.9091)*(B-25.9091)	0.0276794	0.009596	2.88	0.0078*

Prediction Profiler



The most significant term here is the Prescribed Second Operational Tour Length 2OP. With a positive slope, any change to 2OP has a proportional effect on Observed Mean Second Operational Tour Length.

The interaction between Batch Size B and 2OP indicates that changes to either factor affect the magnitude of the impact of the other factor on the Mean 2OP Tour Length. The interaction between B and graduation rate t_A can also be described as having the same characteristics.

Graduation rate is the next significant term. With a positive slope, a change in t_A has a proportional effect on the Observed Mean Second Operational Tour Length.

Finally, as Batch Size B increases, the tour lengths will be decreased. However, the presence of a non-linear term in B indicates diminishing returns to scale for this effect.

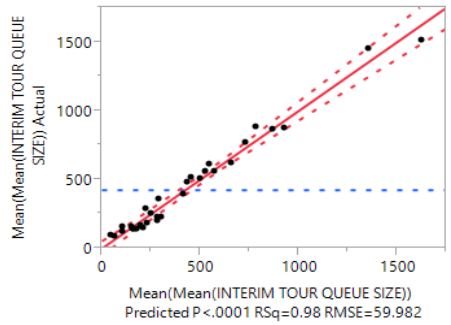
4. Mean Interim Queue Size

Our next metamodel has all five factors as input variables and the Mean Interim Queue Size as the dependent variable. The model indicates very good predictive power as indicated by an adjusted R^2 value of 0.9735. Parameter estimates for each of the coefficients for the final stepwise regression are displayed in Figure 19. Note that parameter estimates for the two excluded input factors are not reflected in the model due to their statistical insignificance.

Figure 19. Model—Mean Interim Queue Size

Response Mean(Mean(INTERIM TOUR QUEUE SIZE))

Actual by Predicted Plot



Summary of Fit

RSquare	0.978502
RSquare Adj	0.973541
Root Mean Square Error	59.98211
Mean of Response	422.897
Observations (or Sum Wgts)	33

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	4257757.7	709626	197.2360
Error	26	93544.2	3598	Prob > F
C. Total	32	4351301.9		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-372.9226	105.3932	-3.54	0.0015*
B	35.038597	1.582973	22.13	<.0001*
T_A	-348.1309	35.09703	-9.92	<.0001*
2OP	23.030072	1.178701	19.54	<.0001*
(B-25.9091)*(T_A-2.50002)	-22.66893	5.084311	-4.46	0.0001*
(B-25.9091)*(2OP-33.0303)	1.9972419	0.207525	9.62	<.0001*
(T_A-2.50002)*(2OP-33.0303)	-16.61523	5.401913	-3.08	0.0049*

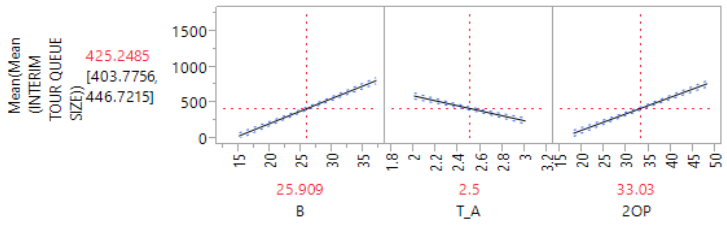
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
B	1	1	1762746.0	489.9438	<.0001*
T_A	1	1	353987.3	98.3885	<.0001*
2OP	1	1	1373494.7	381.7539	<.0001*
B*T_A	1	1	71522.3	19.8792	0.0001*
B*2OP	1	1	333244.4	92.6231	<.0001*
T_A*2OP	1	1	34037.8	9.4606	0.0049*

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
B	35.038597	1.582973	22.13	<.0001*
2OP	23.030072	1.178701	19.54	<.0001*
T_A	-348.1309	35.09703	-9.92	<.0001*
(B-25.9091)*(2OP-33.0303)	1.9972419	0.207525	9.62	<.0001*
(B-25.9091)*(T_A-2.50002)	-22.66893	5.084311	-4.46	0.0001*
(T_A-2.50002)*(2OP-33.0303)	-16.61523	5.401913	-3.08	0.0049*

Prediction Profiler



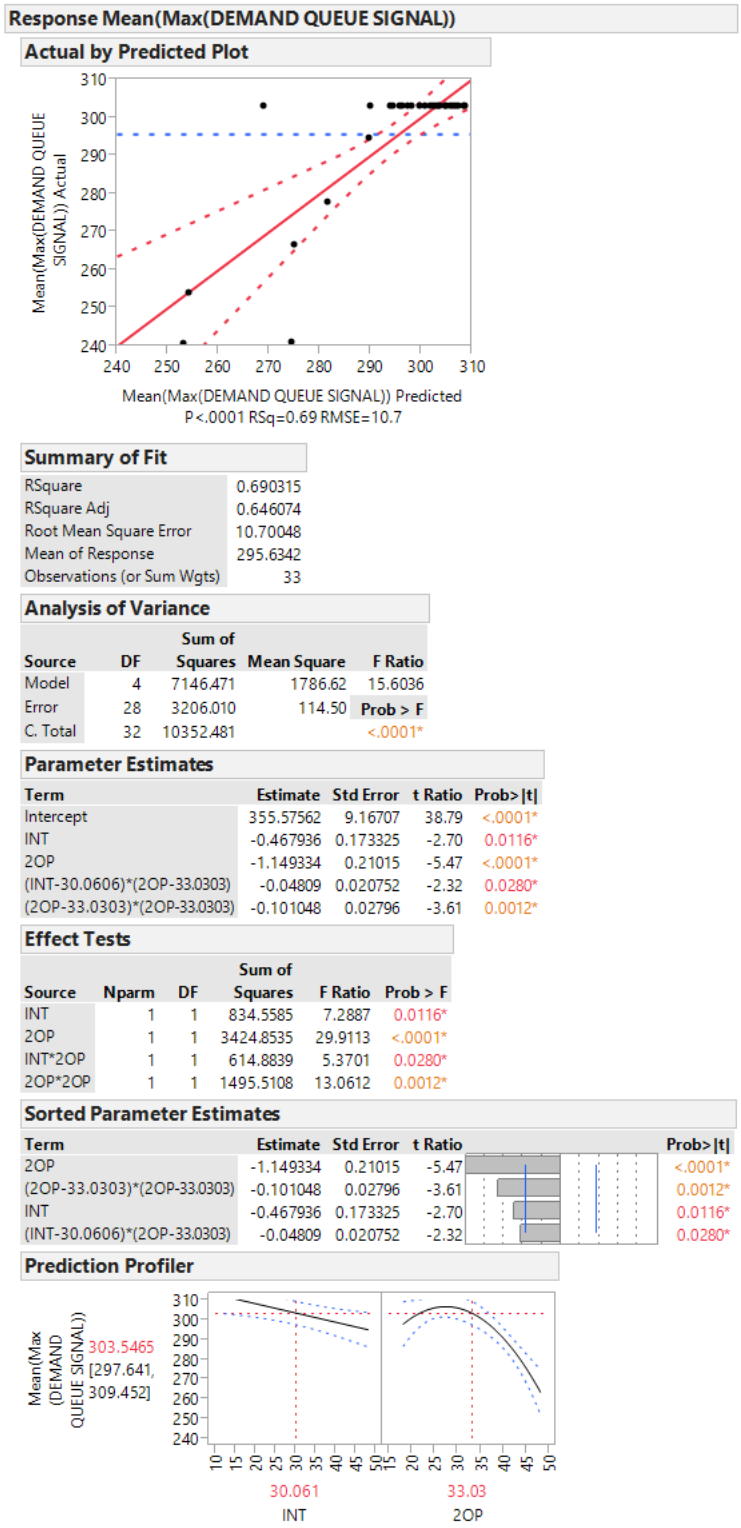
Both Batch Size B and Prescribed Second Operational Tour Length 2OP have a significant impact on Mean Interim Queue Size. Intuitively, this makes sense. If we think of the Interim Tour queue as a buffer, Batch Size as the depositor, and Second Operational Tour Length as the withdrawal, then the positive slope of both terms is logically sound. An increase in Batch Size (i.e., in deposits), contributes to a larger Mean Queue size. An increase in the Prescribed Second Operational Tour Length reduces the numbers of demands placed on the system, which in turn reduces the number of withdrawals—a net increase in the Mean Interim Queue size. The same analogy can be used for B and 2OP with respect to the graduation rate t_A.

Finally, there are interactions among the factors—changes to either factor in any of the interactions affects the magnitude of the impact the other factor has on the Mean Interim Queue size.

5. Demand Model

For this model, we took the maximum of Unmet Demand across 100 replications for each of the 33 design points. With a dataset consisting of 3300 maximums, we summarized the data, by group (factor level setting) in order to obtain the Mean Maximum Unmet Demand for each of the 33 design points. Our goal is to build a metamodel that will help minimize Mean Maximum Unmet Demand. The resulting regression model gives us insight, but has weaker predictive power than our previous models with an adjusted R^2 value of 0.6460. Parameter estimates for each of the coefficients in the final stepwise regression are displayed in Figure 20.

Figure 20. Model—Mean Maximum Unmet Demand

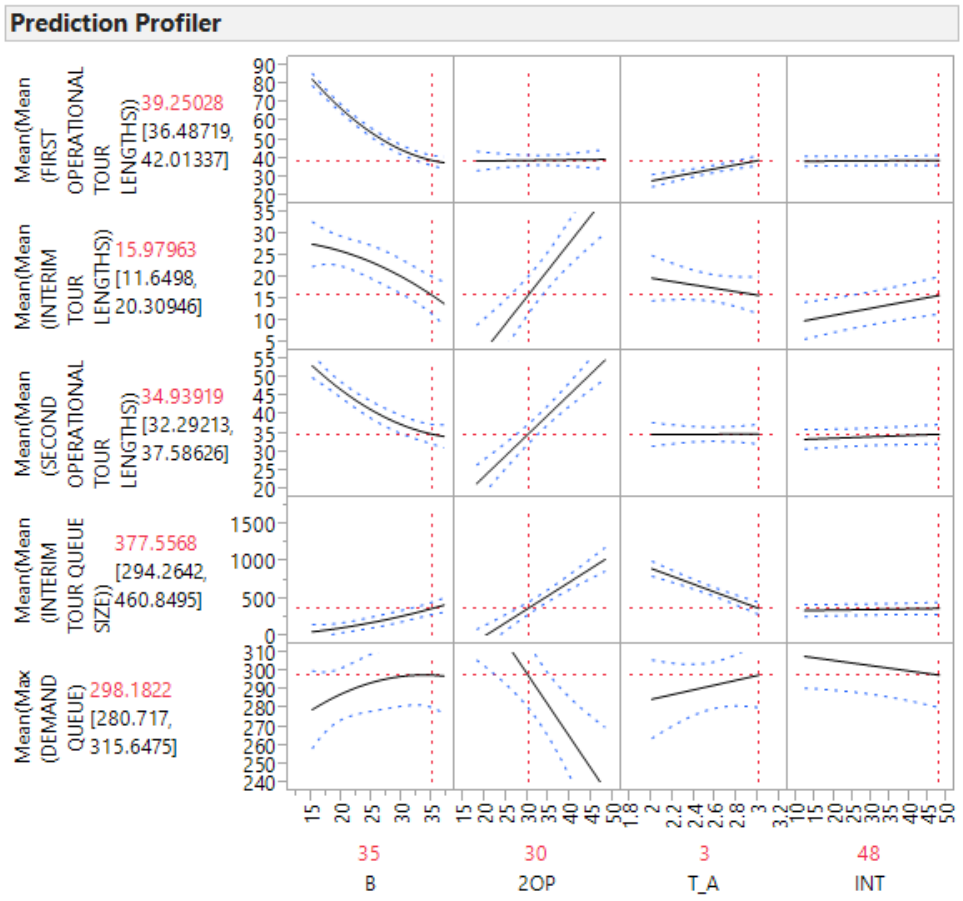


Note that only two of our five factors have any impact on the Observed Mean Maximum Unmet Demand. Parameter estimates for the three excluded input factors are not reflected in the model due to their statistical insignificance. The dominant factor is the Prescribed Second Operational Tour 2OP Length—with both a linear and 2nd order term. If 2OP is increased, then Observed Mean Maximum Unmet Demand will be decreased. However, the presence of the non-linear terms in 2OP indicates an increase in returns to scale for this effect. The Prescribed Interim Tour Length INT is also significant, and has a negative slope—as the Prescribed Interim Tour Length increases, the Observed Mean Maximum Unmet Demand decreases proportionally. Finally, there is an interaction between the two factors INT and 2OP—a change to either factor affects the magnitude of the impact of the other factor on the Observed Mean Maximum Unmet Demand.

6. Composite Model

We placed the same factors, interactions, and second order terms derived from our previous models as regressors for our multivariate regression—refitting of this model using stepwise regression was not performed. The resulting prediction profiler, depicted in Figure 21, will allow us to select desired factor levels, while observing the effects on all of the performance measures simultaneously. This gives us the ability to assess tradeoffs that may exist as we seek to reach target levels of performance for all of the MOEs. For our baseline values, we selected the current PERS-4412 policy of B = 25, t_A = 3.0, INT=36, and 2OP=24 for our independent variables.

Figure 21. Prediction Profiler—Composite Model



In looking at Figure 21, the Y axis shows the results (independent variables) from each of the regressions (Standard Least Squares) while the X axis shows the common set independent variables. The parameter estimates for each of the regressions differed slightly in value and often included more single order terms and factorial combinations.

An initial result to note is that 1OP was not significant in any of the models we constructed. In retrospect, this makes sense because newly arriving officers to the system displace First Operational Tour incumbents on a 1:1 ratio without regard to the incumbent's TOS.

In terms of impact on the Observed Mean Interim Queue size, we can immediately see from Figure 21 that Prescribed Interim Tour Length has minimal impact

on any MOEs other than Observed Mean Interim Tour Length and Observed Mean Maximum Unmet Demand (as indicated by their slopes).

Another result to note is that any change in the Prescribed Second Operational Tour Length 2OP, with the intent of achieving our other stated objectives, can be offset by changes to the graduation rate t_A (as indicated by their slopes) in order to minimize the difference between the number of funded billets in the Interim Tour (364) and the Observed Mean Interim Tour Length.

Beginning with our primary goal of minimizing the absolute difference between the number of funded Interim Tour billets (364) and the resultant Mean Interim Tour Queue Size we selected the current PERS-4412 policy of B = 25, t_A = 3.0, INT=36, and 2OP=24 for our initial factor levels. Again, the Prescribed First Operational Tour Length 1OP is excluded as its value has no bearing on any outcome.

We then used the Prescribed Interim Tour Length INT to maximize the Observed Mean Interim Tour Length as the other factor levels, except 2OP, have a tendency to drive the Observed Mean Interim Tour Length below the minimum threshold of 12 months (see Table 3). Note that increasing 2OP also increases Observed Mean Interim Tour Length, but this action cannot be counteracted by an increase in t_A where 2OP > 30. The factor level 2OP was adjusted up to 30 to further increase the Observed Mean Interim Tour Length.

With our stated of objective of Minimizing the difference between observed means and prescribed tour lengths in mind, B was then used to make final adjustments in order to minimize the difference between the factor 2OP and the Observed Mean Second Operational Tour Length.

With respect to Observed Mean Maximum Unmet Demand, a trade-off was necessary as any adjustment to the other factors, in order to minimize Observed Mean Maximum Unmet Demand, would have come at the expense of our other stated objectives: 1) Observed Mean Interim Tour Length above the accepted minimum; and 2) minimizing the absolute difference between the number of approved Interim Tour billets of 364 and the Mean Interim Queue Size. We did not and could not adjust factor

levels in order to minimize the Observed Mean Maximum Unmet Demand without compromise to our primary objective.

An important distinction is also worth noting here. Maximum Unmet demand is short lived as Second Operational Tour reliefs are provided based on their availability and filled almost immediately—after accounting for leave by the officer. It is reasonable to predict that a decrease in Maximum Unmet Demand is correlated with an increase in Planned Second Operational Tour Lengths, as 2OP incumbents are forced to remain in their billets longer than prescribed.

V. RESULTS, RECOMMENDATIONS, AND CONCLUSIONS

A. RESULTS

A clear set of objectives must be stated before attempting to prescribe factor settings to achieve acceptable performances for our MOEs. Based on the author's experience, controlling the Interim Queue Size (Q) was considered the dominant objective as the number of funded billets is limited. The U.S. Navy currently has 364 funded billets allocated for the Interim Queue. In practice, a larger queue means more bodies, which translates to higher personnel costs. Any growth over this is a surplus in manpower for the jobs that are available. Our objective was to maintain the mean size of the Interim Queue at 364.

Using the composite model, we began by setting each of the factor levels in the prediction profiler as close to the current PERS-4412 policy as possible—B=25, t_A=3.0, INT=36, and 2OP=24—while observing the mean size of the Interim Queue as we adjusted each factor level to meet our stated objective. The resulting solution—which minimized the absolute difference between the Mean Interim Queue Size and the number of funded billets of 364—had the class size at 35 students, a graduating class every three months, and the Prescribed Interim and Second Operational Tour lengths set at 48 months and 30 months, respectively. The choice for the 1OP factor level does not matter since the exchange ratio between new accessions and incumbents is 1:1. The results are summarized in Table 5.

Table 5. Factor Level Solutions—Composite Model

Summary Results	**Mean**	**Lower CI**	**Upper CI**	
Observed Mean First Operational Tour Length	39.2503	36.4872	42.0134	
Observed Mean Interim Tour Length	15.9796	11.6498	20.3095	
Observed Mean Second Operational Tour Length	34.9392	32.2921	37.5863	
Observed Mean Interim Queue Size	377.5568	294.2642	460.8495	
Observed Mean Maximum Unmet Demand	298.1822	280.717	315.6475	
Factor	**B**	**T_A**	**INT**	**2OP**
Factor Level	35	3	48	30

A single confirmatory simulation replication using factor levels displayed in Table 5 produced the results displayed in Table 6. Note that the results for Mean Maximum Unmet Demand are well outside the confidence interval—an example of our regression model's predictive power, or lack thereof.

Table 6. Confirmatory Run

Confirmatory Run	Mean
Observed Mean First Operational Tour Length	39.7794
Observed Mean Interim Tour Length	17.9189
Observed Mean Second Operational Tour Length	34.8073
Observed Mean Interim Queue Size	417.6671
Observed Mean Maximum Unmet Demand	115.3053

Our MOE objective covering tour lengths was the only goal not met—to minimize the difference between observed means and prescribed tour lengths. Meeting the prescribed tour length within an acceptable band for the Interim Tour job assignment depends upon our ability to compromise elsewhere. For example, an increase in the Prescribed Second Operational Tour length alleviates the demand for reliefs from within the Interim Tour, but at the expense of a larger Interim queue size.

B. RECOMMENDATIONS FOR FURTHER STUDY

Our model focused on the primary research questions posed by the sponsor—**"What should the tour lengths be for each officer in their successive assignments to a First Operational, Interim, and Second Operational Tour?"** However, we suggest several possible avenues for future study, which have potential to improve both the model and any policy recommendations that may be derived from it.

The lack of data prevented us from modeling attrition. Incorporating attrition would be more representative of the real-world system, and would likely improve the model.

Officers do not arrive in neat uniform batches and at the same time (due to accession sources), nor do all officers progress from one operational tour to the next while being guaranteed a break in-between. Distributional modeling of accessions and tour progression has the potential to improve the model, and can be initially studied using designed experiments to determine the potential benefits of collecting real-world data on these phenomena.

C. CONCLUSIONS

Our efforts in model building and analysis resulted in a tool tailored for a single purpose. We acknowledge that the limited scope of our study probably left a lot more questions unanswered than answered. However, the result of many hours of coding, debugging, and analysis resulted in a suite of statistical models that yield insight into the cause-and-effect relationship between four of the factors that are within the sponsor's control and the corresponding operational tour characteristics. The model's predictive capabilities, including the associated profilers, are themselves dynamic tools that the end user can utilize to address a wide variety of what-if questions.

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